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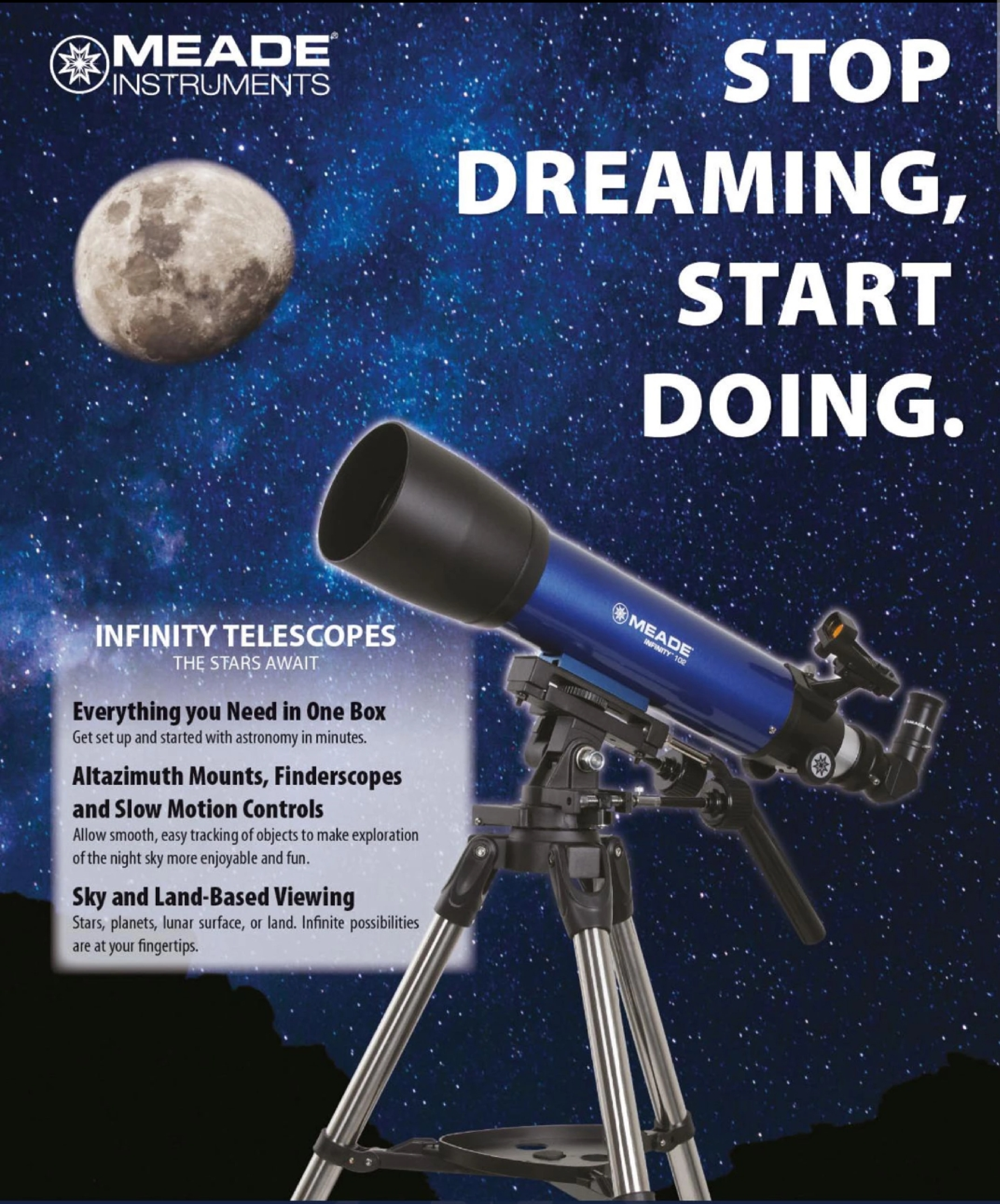

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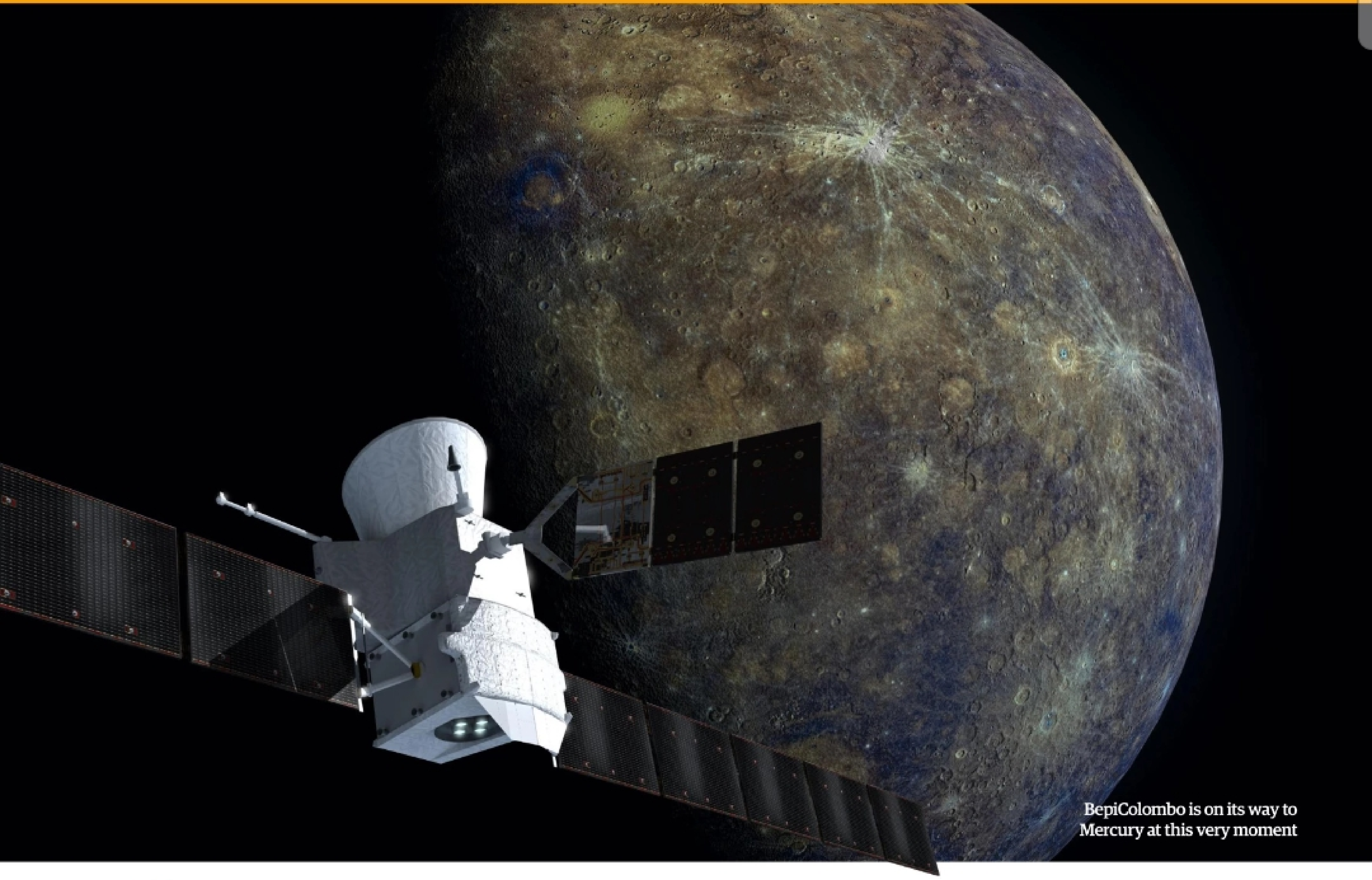

BepiColombo is on its way to Mercury at this very moment

Welcome

The star of the month this issue - and let's be honest, it has been for the past few weeks - is red supergiant Betelgeuse. If you've been following the latest on the swollen member of the constellation Orion or have even observed it yourself, then you'll know that its weird dimming and brightening over a long period of time has got astronomers talking. So why the fuss? It's taken over 150 years of observations for something notable to happen, earmarking it as the next supernova candidate.

Understandably, astronomers - whether they're professional or amateur - are waiting for the inevitable to happen, and while they're hoping for the sky to be lit up by the equivalent of 10,000 Suns, they reveal to **All About Space** the real reason behind the supermassive star's exceedingly strange behaviour.

Also this issue, we're all about Mercury, with BepiColombo ready to unlock the smallest planet in our Solar System's secrets and a whole deluge of fascinating discoveries from the tiny world's cratered surface that have popped up over time, we promise that you'll find out something new. That's not all you'll find in the 101st instalment of **All About Space**: we reveal what really happened to the animals blasted off into outer space and provide our regular guide to the night sky. We're also offering you the chance to win Celestron binoculars! See you next month.

Gemma Lavender
Editor-in-Chief

Our contributors include...

James Romero
Space science writer
Is Betelgeuse going to be our next supernova? Join James as he uncovers what its recent unusual behaviour means for the supergiant star's future.

Andrew May
Science writer
What's new at the Solar System's swiftest planet? Andrew uncovers the latest discoveries at Mercury – we guarantee you'll find out something new.

David Rothery
Planetary scientist
David provides the lowdown on mission to Mercury BepiColombo and what the surface tells us about the pint-sized planet's early history.

Ben Skuse
Space science writer
What happened to the world's animal astronauts? From space dogs to water bears, each and every one of these creatures has contributed to science.

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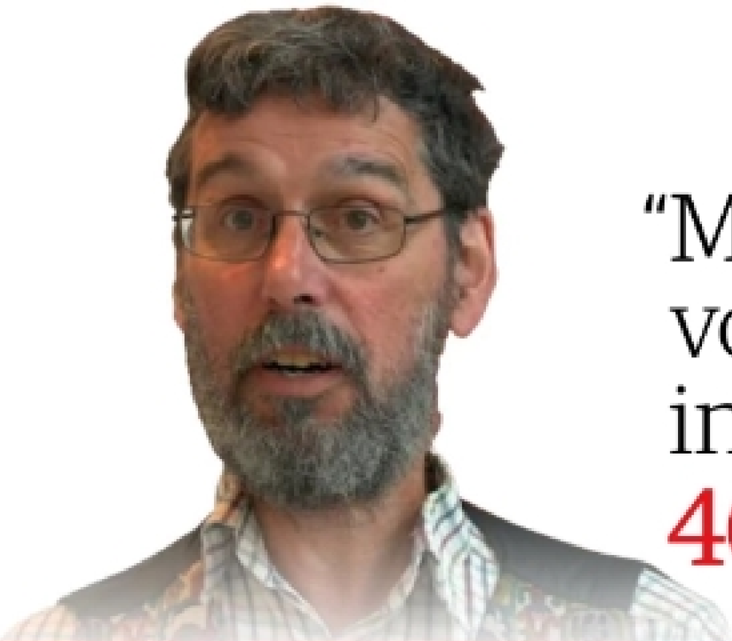

"Mercury is covered in craters, volcanic planes and holes ripped in the ground"

46 David Rothery, principal investigator for the Mercury Imaging X-ray Spectrometer on BepiColombo

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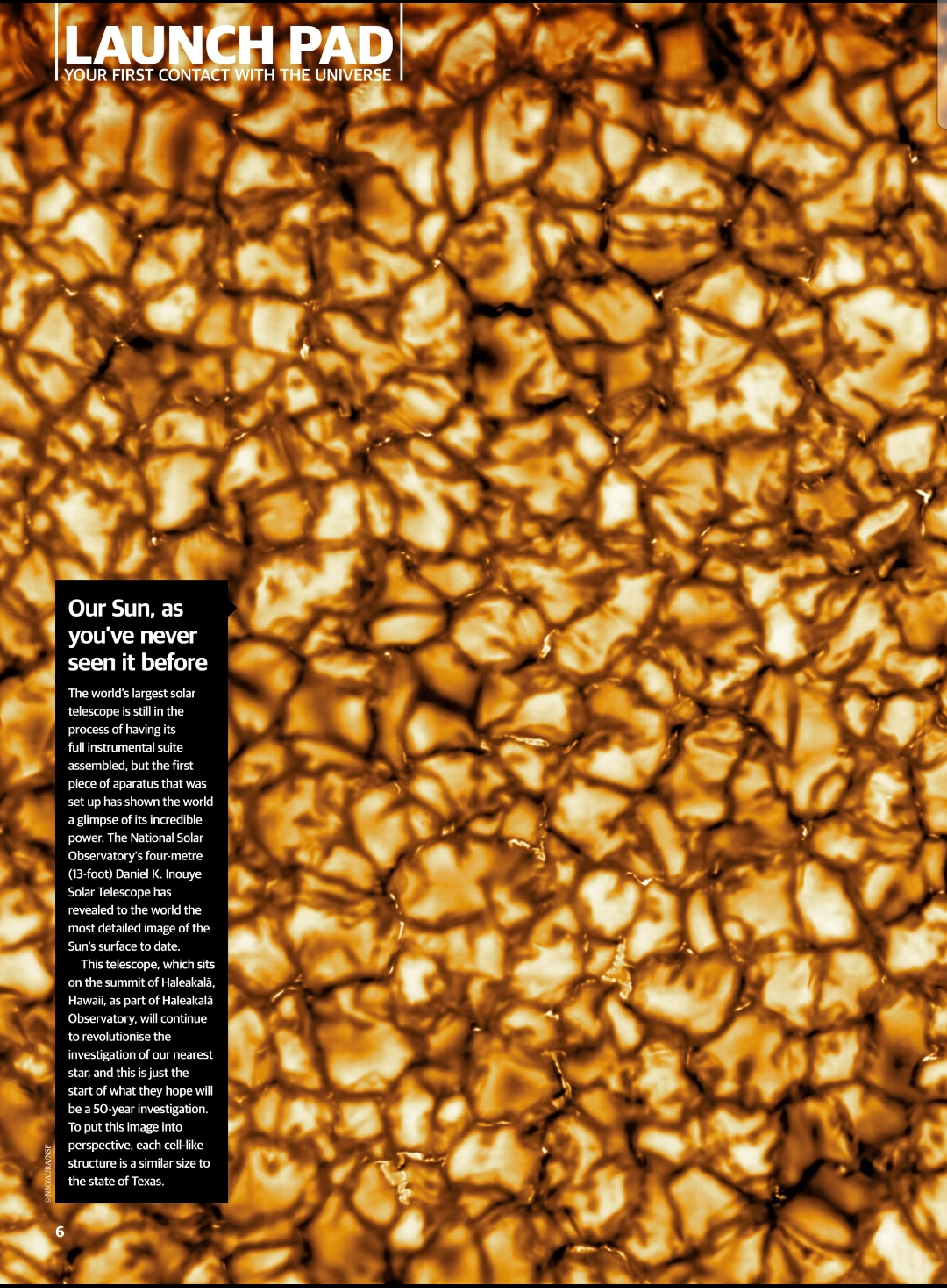

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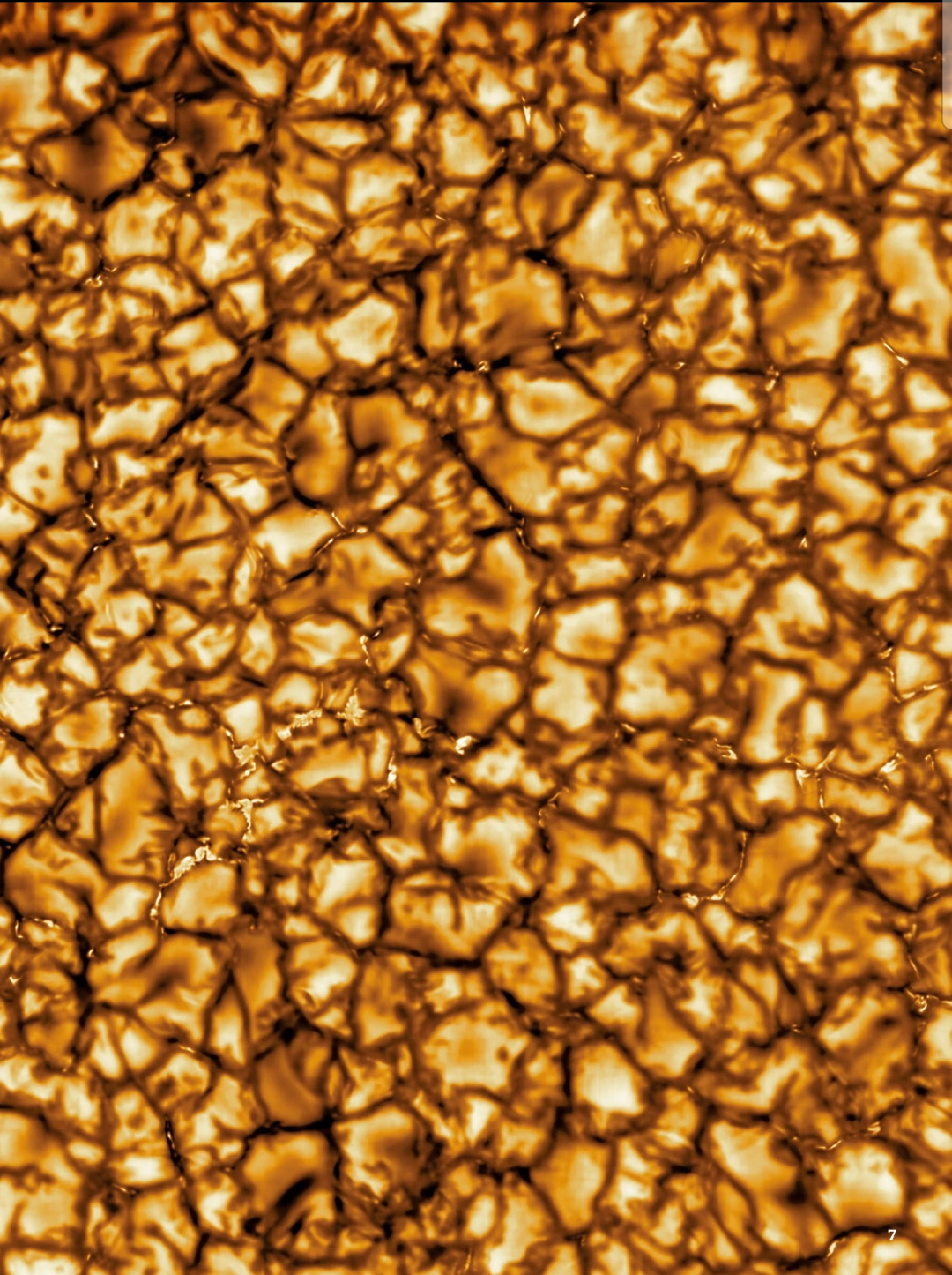
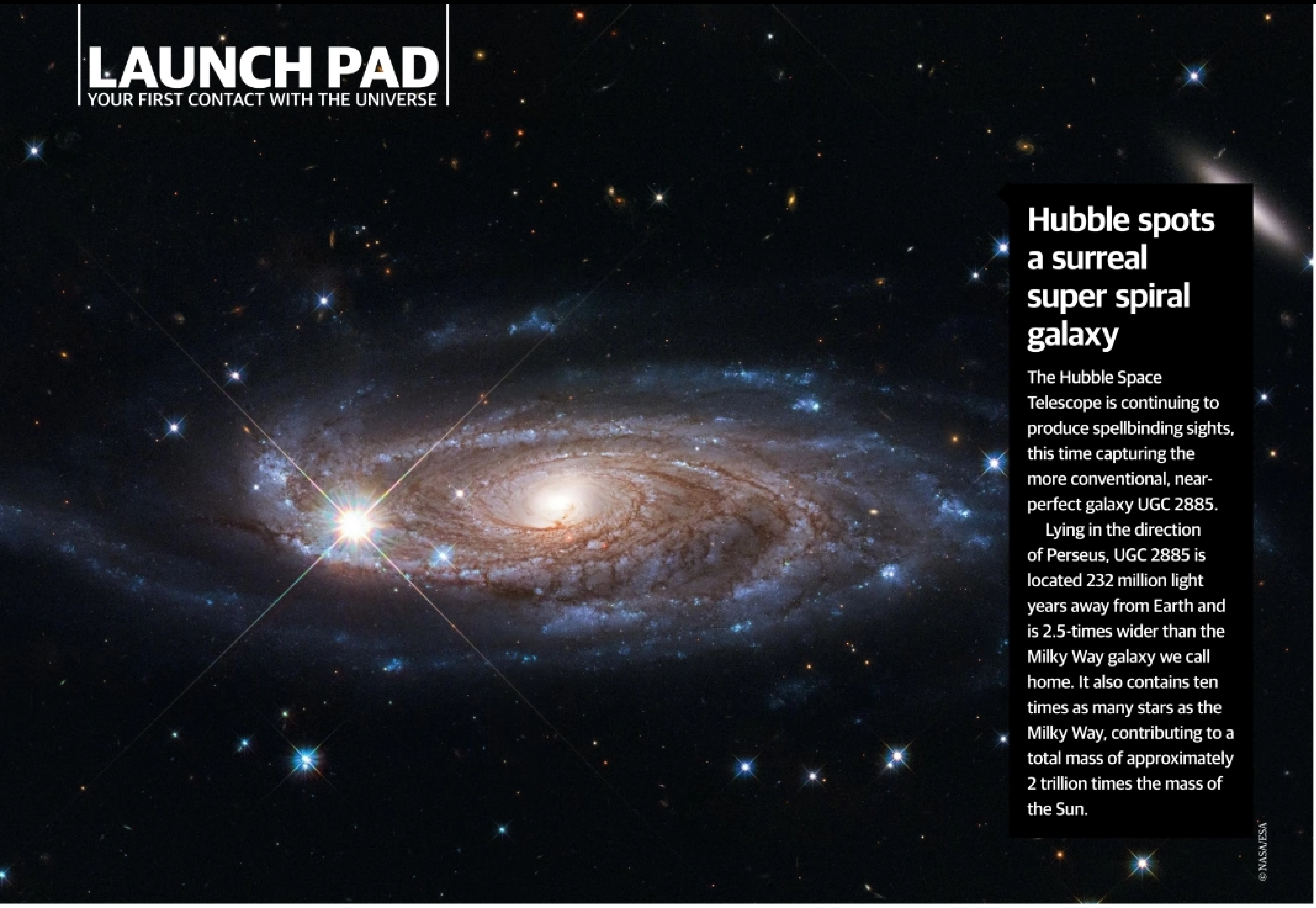
Our Sun, as you've never seen it before

The world's largest solar telescope is still in the process of having its full instrumental suite assembled, but the first piece of aparatus that was set up has shown the world a glimpse of its incredible power. The National Solar Observatory's four-metre (13-foot) Daniel K. Inouye Solar Telescope has revealed to the world the most detailed image of the Sun's surface to date.

This telescope, which sits on the summit of Haleakalā, Hawaii, as part of Haleakalā Observatory, will continue to revolutionise the investigation of our nearest star, and this is just the start of what they hope will be a 50-year investigation. To put this image into perspective, each cell-like structure is a similar size to the state of Texas.





Hubble spots a surreal super spiral galaxy

The Hubble Space Telescope is continuing to produce spellbinding sights, this time capturing the more conventional, near-perfect galaxy UGC 2885.

Lying in the direction of Perseus, UGC 2885 is located 232 million light years away from Earth and is 2.5-times wider than the Milky Way galaxy we call home. It also contains ten times as many stars as the Milky Way, contributing to a total mass of approximately 2 trillion times the mass of the Sun.

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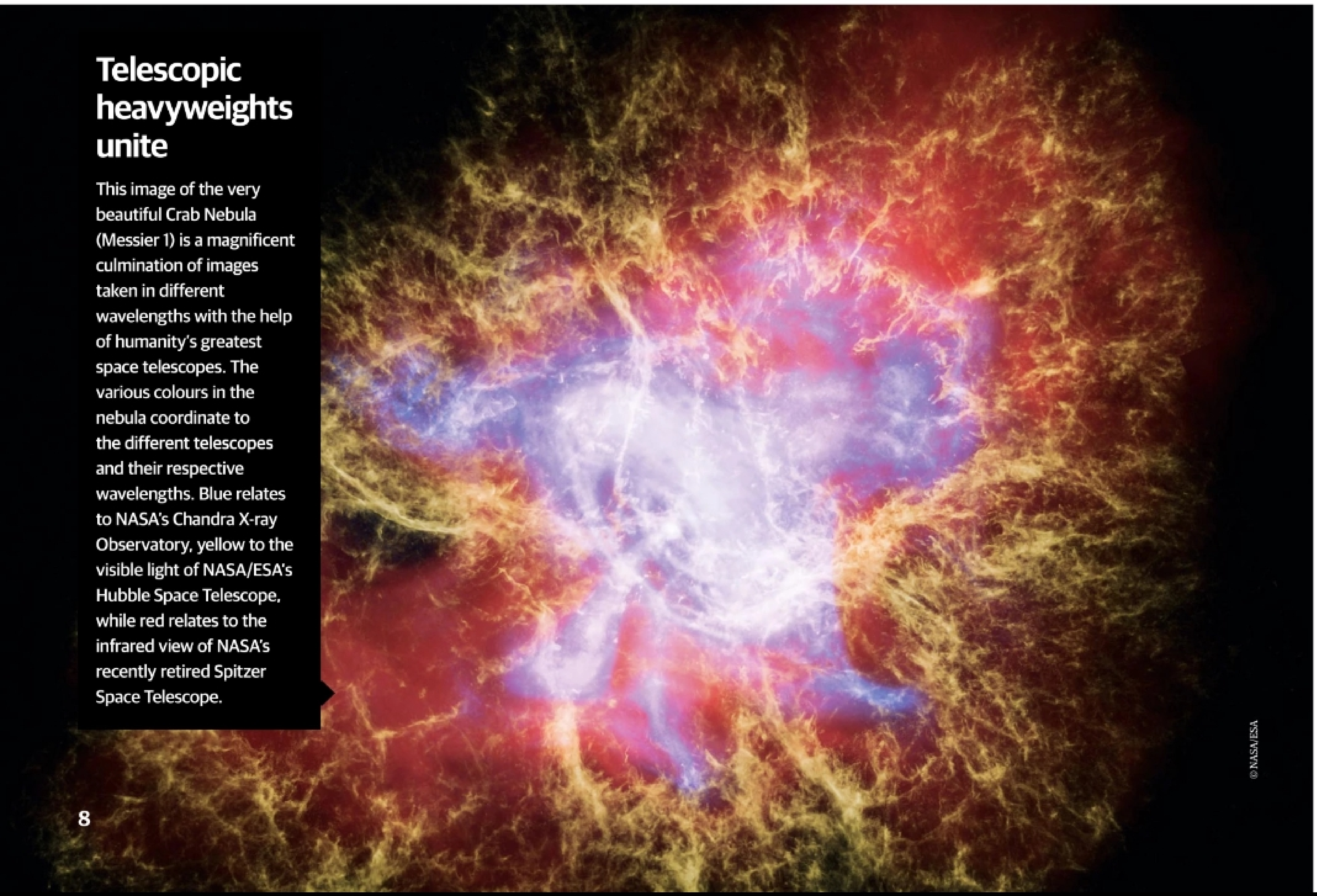

Telescopic heavyweights unite

This image of the very beautiful Crab Nebula (Messier 1) is a magnificent culmination of images taken in different wavelengths with the help of humanity's greatest space telescopes. The various colours in the nebula coordinate to the different telescopes and their respective wavelengths. Blue relates to NASA's Chandra X-ray Observatory, yellow to the visible light of NASA/ESA's Hubble Space Telescope, while red relates to the infrared view of NASA's recently retired Spitzer Space Telescope.

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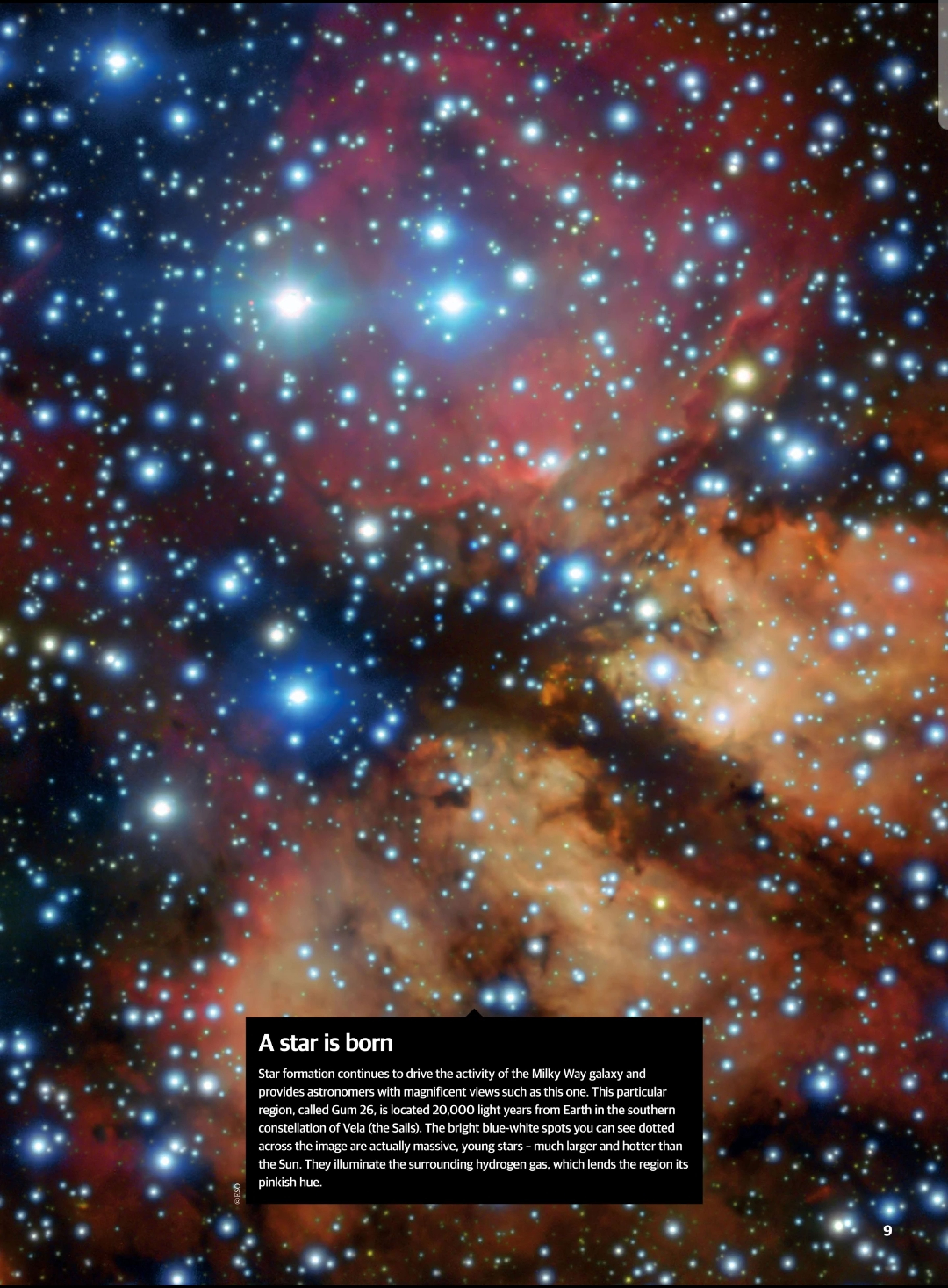

A star is born

Star formation continues to drive the activity of the Milky Way galaxy and provides astronomers with magnificent views such as this one. This particular region, called Gum 26, is located 20,000 light years from Earth in the southern constellation of Vela (the Sails). The bright blue-white spots you can see dotted across the image are actually massive, young stars – much larger and hotter than the Sun. They illuminate the surrounding hydrogen gas, which lends the region its pinkish hue.

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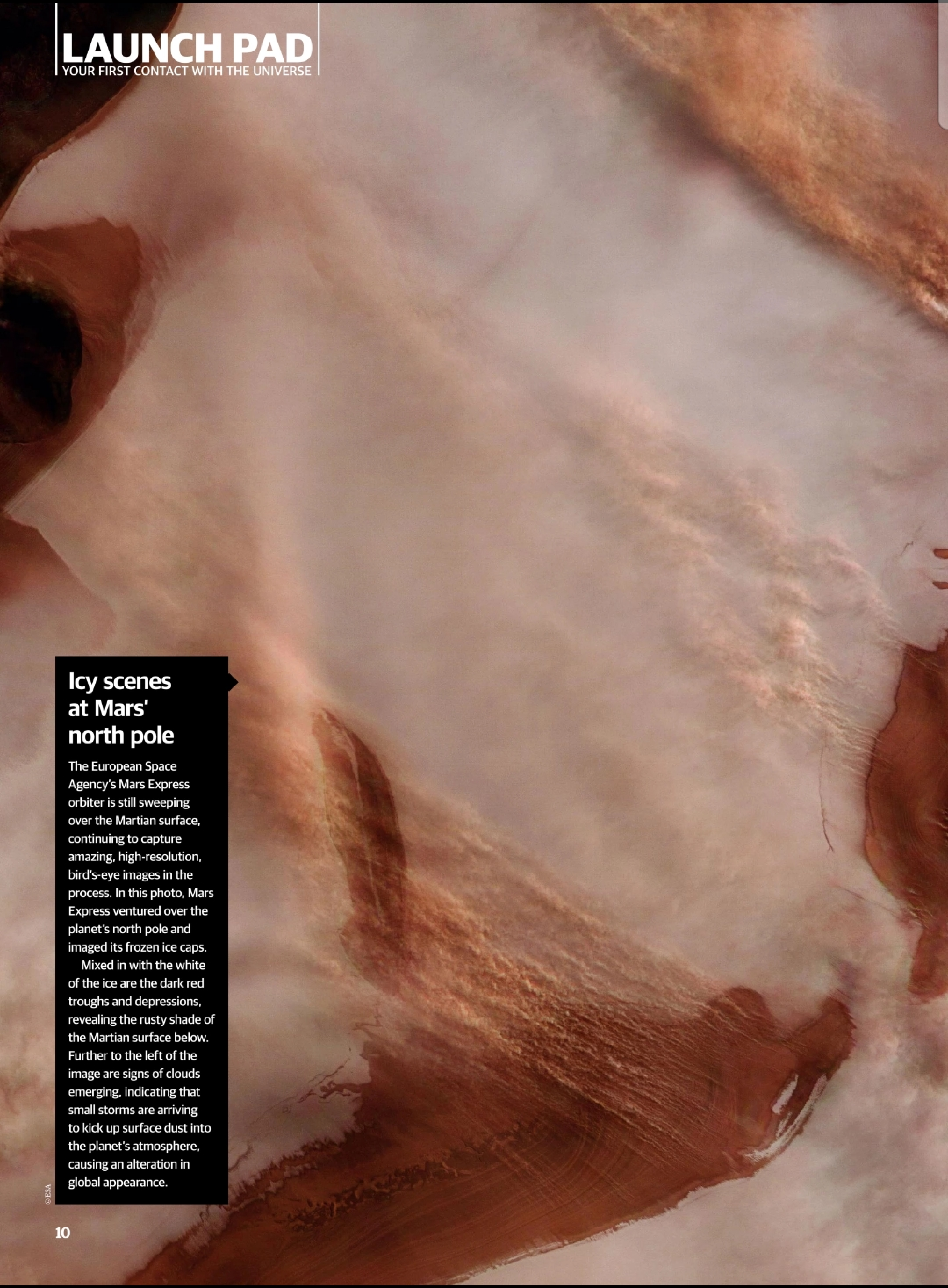

Icy scenes at Mars' north pole

The European Space Agency's Mars Express orbiter is still sweeping over the Martian surface, continuing to capture amazing, high-resolution, bird's-eye images in the process. In this photo, Mars Express ventured over the planet's north pole and imaged its frozen ice caps.

Mixed in with the white of the ice are the dark red troughs and depressions, revealing the rusty shade of the Martian surface below. Further to the left of the image are signs of clouds emerging, indicating that small storms are arriving to kick up surface dust into the planet's atmosphere, causing an alteration in global appearance.

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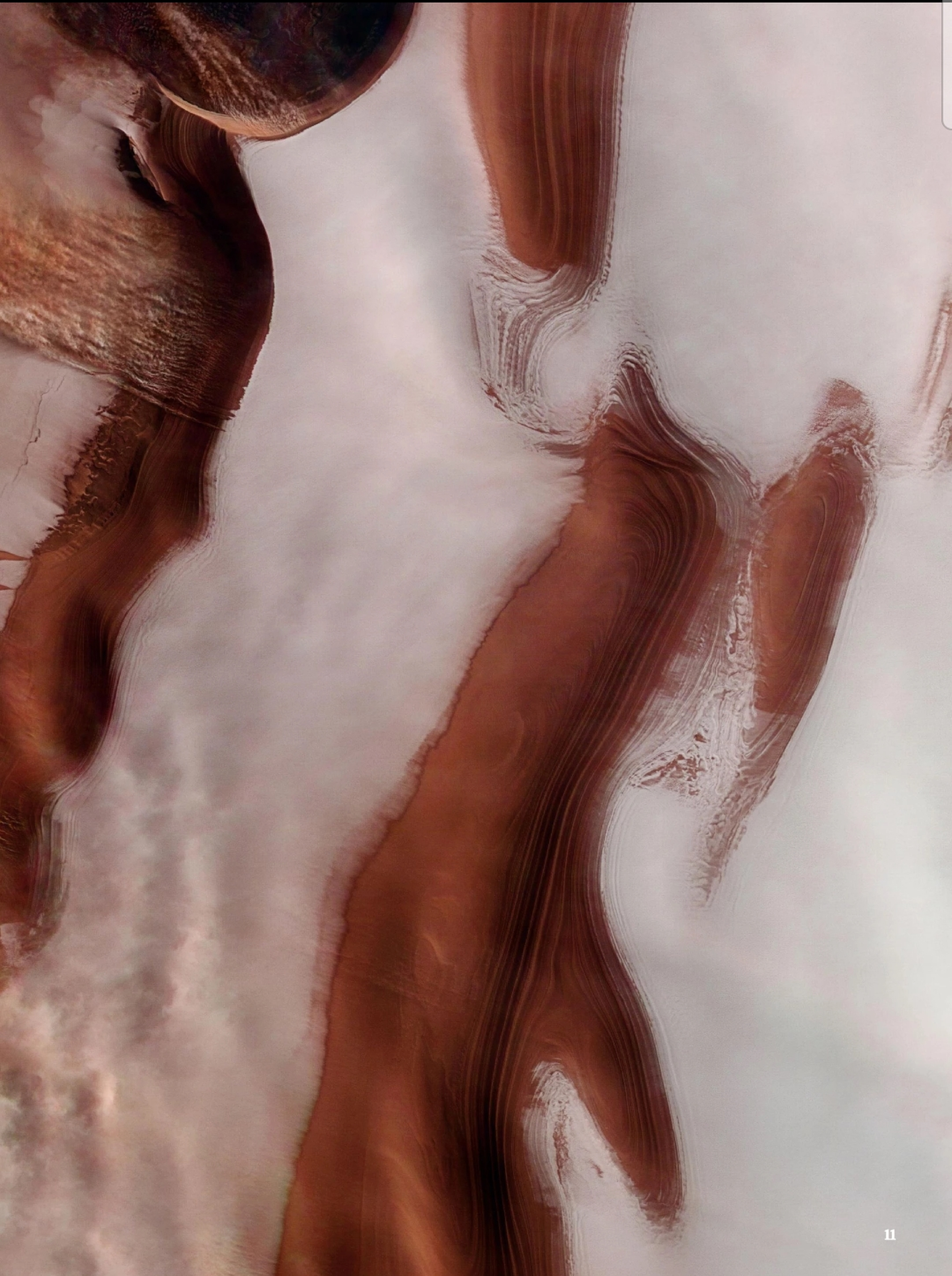


By studying how gravitons and photons might interact, we could detect these waves better

Photons could uncover 'massive gravity', brand new theory suggests

Words by Rafi Letzter

Gravitational waves, ripples in space-time, slip through Earth all the time, carrying secrets about the universe. Until a few years ago we couldn't detect these at all, and even now we have only a basic ability to detect the stretching and squeezing of the cosmos. A proposed new gravitational-wave hunter, which would measure how particles of light and gravity interact, could change that. In the process it could answer big questions about dark energy and the universe's expansion.

The detectors on Earth today, called the Laser Interferometer Gravitational-Wave Observatory (LIGO) and Virgo, operate according to the same principle: as a gravitational wave moves through the Earth, it faintly stretches and squeezes space-time. By measuring how long a laser light takes to travel over long distances, the detectors notice when the size of that space-time changes. But the changes are minute, requiring extraordinarily sensitive equipment and statistical methods to detect.

A team led by Subhashish Banerjee, a physicist at the Indian Institute of Technology in Jodhpur, India, proposed a radical new method: hunting gravitational waves by looking for effects of direct interactions between gravitons – theoretical particles that carry gravitational force – and photons, the particles that make up light. By studying those photons after they've interacted with gravitons, you should be able to reconstruct properties of a gravitational wave. Such a detector would be much cheaper and easier to build than existing detectors, Banerjee said. "Measuring photons is something which people know very well," said Banerjee. "It's extremely well-studied, and definitely it is less challenging than a LIGO kind of set-up."

No one knows exactly how gravitons and photons would interact, largely because gravitons are still entirely theoretical. But the researchers made a series of theoretical predictions. When a stream of gravitons hits a stream of photons, those photons should scatter. That scattering would produce a faint, predictable pattern, which physicists could amplify and study using techniques developed by quantum physicists who study light.

Linking the physics of the tiny quantum world with the large-scale physics of gravity and relativity has been a goal of scientists since Albert Einstein's time. But even though the newly suggested approach to studying gravitational waves would use quantum methods, it wouldn't fully bridge that tiny-to-large-scale gap on its own, Banerjee said. Probing the direct interactions of gravitons might solve some other deep mysteries about the universe, though, he added.

Banerjee and his team showed that the way the light scatters would depend on the specific physical properties of gravitons. According to Einstein's theory of general relativity, gravitons are massless and travel at the speed of light. But according to a collection of theories, together known as 'massive gravity', gravitons have mass and move slower than the speed of light. These ideas, some researchers think, could resolve problems such as dark energy and the expansion of the universe. Detecting gravitational waves using photon scattering, Banerjee said, could have the side-effect of telling physicists whether massive gravity is correct.

© Getty

'Flammable ice' could be key in discovering alien life

Words by Chelsea Gohd

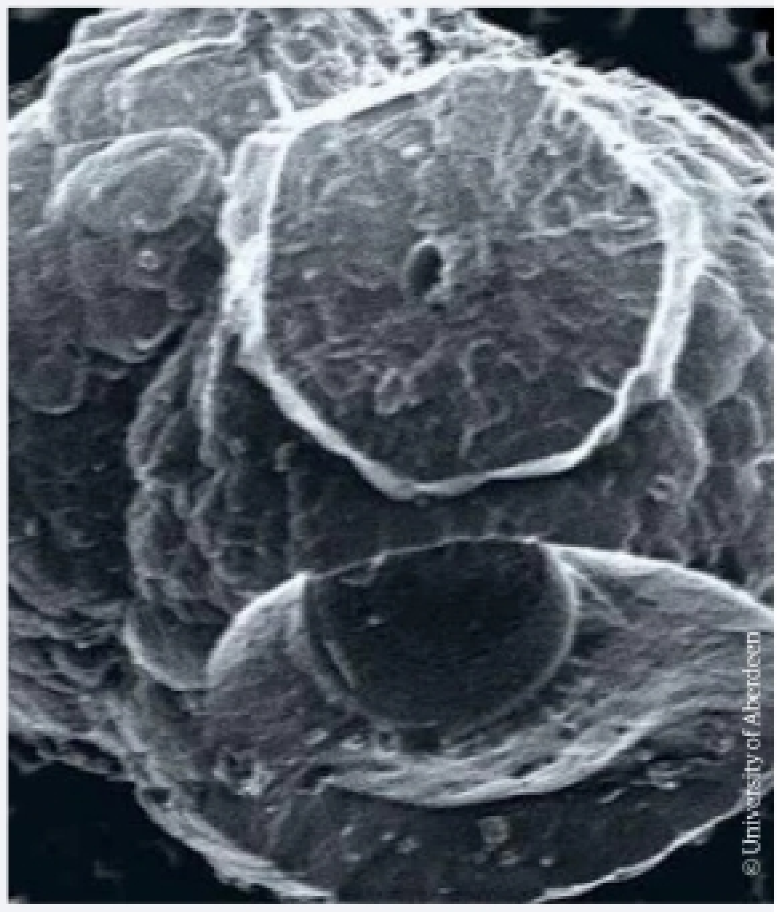
Flammable ice, also known as methane hydrate, is created when methane gas is trapped within ice's molecular structure. Sheets of this frozen gas and ice contain microscopic bubbles of oil and water. Scientists studying 'flammable ice' in the Sea of Japan found microscopic, living creatures within these tiny bubbles.

The researchers chanced upon this discovery in a unique manner. While melting hydrate to study the methane gas it contains, Glen T. Snyder, a researcher at Meiji University, noticed a powder with little microscopic spheroids in it that contained tiny spheres with dark centres in them.

"In combination with the other evidence collected by my colleagues, my results showed that even under near-freezing temperatures, at extremely high pressures, with only heavy oil and saltwater for food sources, life was flourishing and leaving its mark inside these little bubbles in the 'flammable ice'," said Stephen Bowden of the University of Aberdeen's School of Geosciences in Scotland.

So how does this work inform the search for extraterrestrial life? "The methane in methane hydrate is known to form as microbes degrade organic matter on the seafloor. But what we never expected to find was microbes continuing to grow and produce these spheroids, all of the time while isolated in tiny, cold, dark pockets of saltwater and oil," Snyder said. "It certainly gives a positive spin to cold, dark places, and opens up a tantalising clue as to the existence of life on other planets."

Right: Bubbles in the ice contain microscopic life forms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A single grain of Apollo Moon dust opens up a world of lunar science

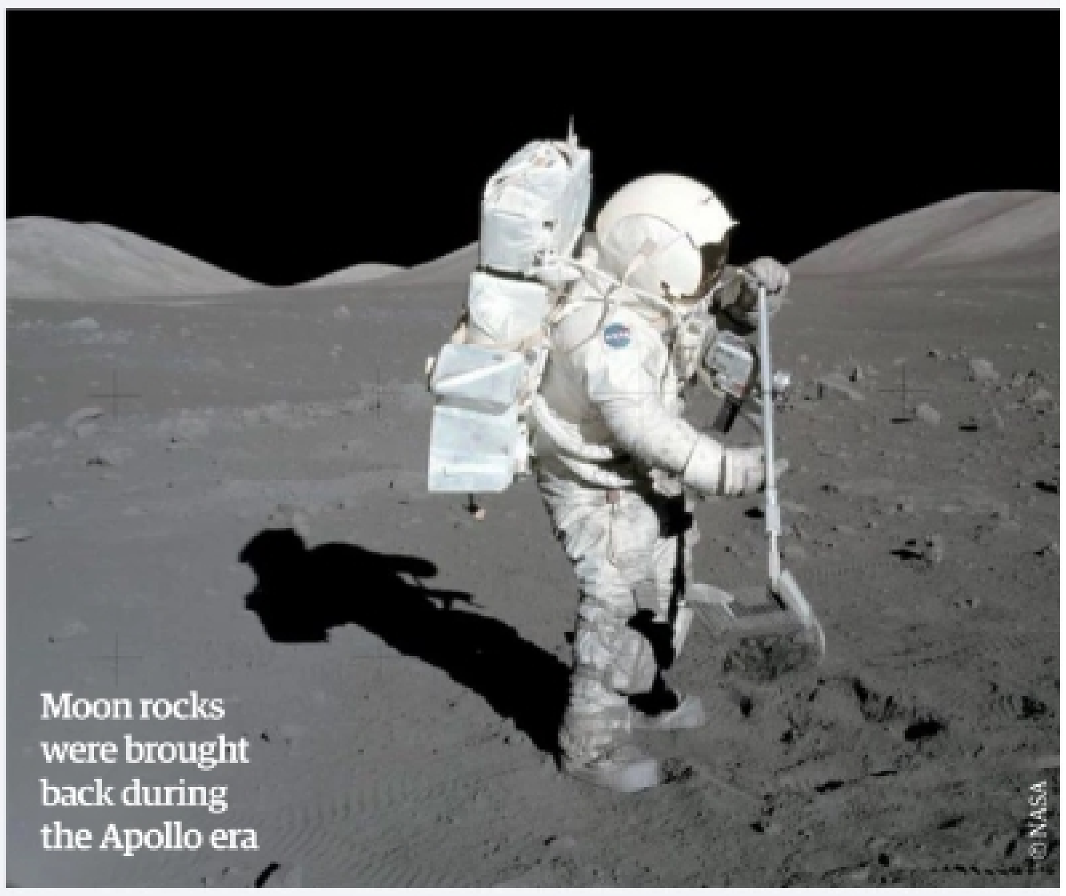
Words by Elizabeth Howell

A team of scientists set out to find a way to analyse Moon dust based on only a single grain of the material. The researchers reported their results in a new study that analyses a single grain of Moon dust gathered in 1972 by astronauts on the Apollo 17 mission. "We're analysing rocks from space, atom by atom," revealed Jennika Greer, a doctoral student in geophysical sciences at the University of Chicago. "It's the first time a lunar sample has been studied like this. We're using a technique many geologists haven't even heard of."

"We can apply this technique to samples no one has studied," Philipp Heck, a curator at the Field Museum, said. "You're almost guaranteed to find something new or unexpected. This technique has such high sensitivity and resolution, you find things you wouldn't find otherwise and only use up a small bit of the sample."

Researchers use the technique, called atom probe tomography, to learn more about the Moon's history. For example, scientists can analyse samples to figure out how water and helium formed on the Moon. Both compounds could be useful resources for future landing missions, the first of which NASA is planning for 2024. In the sample of Moon dust – or regolith – that she analysed, Greer found water, helium, iron and even traces of weathering caused by the exposure of the regolith to harsh phenomena in space, including micrometeoroids and radiation.

To find those features she shaved a layer of a few hundred atoms of material from the surface – a sample much thinner than a sheet of paper, which is hundreds of thousands of atoms thick. Then she placed the sample inside an atom probe at Northwestern University in Illinois and used a laser to carefully peel individual atoms off the sample and crash them into a detector plate for analysis.


Moon rocks were brought back during the Apollo era

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NASA's solar probe spots 'stealth' outburst on the Sun

Words by Meghan Bartels

Coronal mass ejections (CMEs) aren't known for being subtle: each event can fling huge amounts of the soup of charged particles called plasma off the Sun and out into the Solar System. In November 2018, as seen from Earth and certain spacecraft, the Sun seemed to be calm… but it wasn't. It was experiencing what scientists call a 'stealth' coronal mass ejection. Conveniently, NASA's Parker Solar Probe was completing its first close pass behind the Sun at the time, putting its instruments in a perfect position to see what was happening on 11 and 12 November during this usually cryptic event.

"If you've ever seen a CME image, you normally see a lot of activity in these images," Kelly Korreck, a solar physicist at the Smithsonian Astrophysical Observatory, said. "You would see a large blowout; you would probably see one of these exploding. But there wasn't much there."

Even in some of the Parker Solar Probe data, it wasn't obvious at first what was happening during the incident, Korreck said. "When we looked at this initially - just the thermal data - we didn't necessarily think that there was a coronal mass ejection there." But other observations targeting energetic particles did include the fingerprint of a shock, a phenomenon that usually accompanies a coronal mass ejection. Scientists could also confirm the probe was flying through a coronal mass ejection based on data its instruments were gathering about the magnetic field.

Seeing a stealth coronal mass ejection is a step in the right direction. "They're something that we're not traditionally able to see in the ways that we've previously detected coronal mass ejections," Korreck said. "We're starting to see hints of them with better and better telescope resolution."

Above: The Parker Solar Probe was in the right place at the right time to spot this secretive outburst

© ALMA/ESO

Stellar showdown spawns spectacular rainbow cloud

Words by Samantha Mathewson

Using the Atacama Large Millimeter/submillimeter Array (ALMA), astronomers observed the binary star system called HD 101584, revealing a peculiar gas cloud that is believed to be the result of a confrontation between the two stars, according to the European Southern Observatory.

Data from ALMA and the Atacama Pathfinder EXperiment (APEX) shows that one of the stars grew so large that it engulfed the other. As the smaller star spiralled towards its giant stellar companion, it caused the larger, Sun-like star to shed its outer layers, resulting in the expanding clouds of gas captured in the newly released ALMA images.

Based on the ALMA observations, the researchers suggest the low-mass companion star was captured by the red giant star when it reached a critical size only a few hundred years ago.

Left: Nitrogen winds have been discovered blowing on Pluto

Right: The rainbow resulted from a binary star merger

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Pluto's heart powers icy winds

Words by Mike Wall

The dwarf planet's famous heart-shaped feature, which NASA's New Horizons discovered during its epic July 2015 flyby, drives atmospheric circulation patterns on Pluto.

Most of the action comes courtesy of the heart's left lobe, a 1,000-kilometre (600-mile) wide nitrogen-ice plain called Sputnik Planitia. This exotic ice vaporises during the day and condenses into ice again at night, causing nitrogen winds to blow. These winds carry heat, particles of haze and grains of ice westward, staining the ices there with dark streaks.

"This highlights the fact that Pluto's atmosphere and winds - even if the density of the atmosphere is very low - can impact the surface," said Tanguy Bertrand, an astrophysicist and planetary scientist at NASA's Ames Research Center in California.

And that westward direction is interesting in itself, considering that Pluto spins eastward on its axis. The dwarf planet's atmosphere therefore exhibits an odd 'retrorotation'.

This work revealed the likely presence of westerly winds - a high-altitude variety that races along at least four kilometres (2.5 miles) above the surface and a fast-moving type closer to the ground that follows Sputnik's western edge.

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THE NEXT SUPERNOVA?

We're overdue a spectacular display of stellar fireworks, so where will it come from?

Reported by James Romero

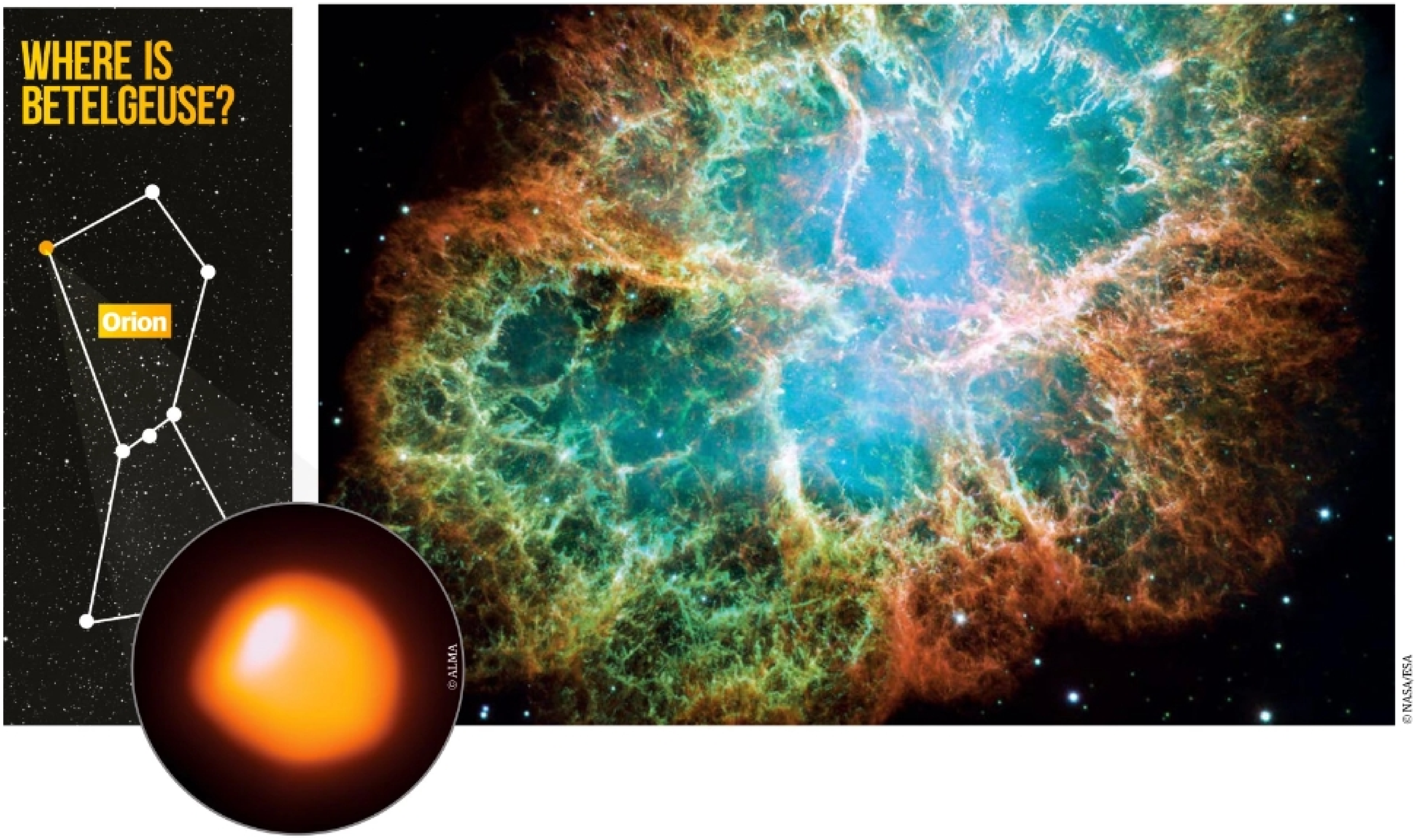
In the near future, the full Moon will have a luminous rival as a cataclysmic event 650 light years away will momentarily shine with the brightness of 10 billion Suns. The after-effects will hang in our sky for many months, and permanently alter our night sky in a way not witnessed in recent human history. Betelgeuse is one of our most recognisable stars. Forming part of the Orion constellation, its bright-red appearance, due to its vast size, has been noted by stargazers since antiquity.

Place Betelgeuse in the exact location of our Sun and the star's equator would extend out to the orbit of Jupiter, with all the inner rocky planets moving along inside its fiery outer atmosphere. For the majority of people living under light-polluted city skies without a telescope, Betelgeuse is likely the largest object they will ever set their eyes on.

In recent months, however, it has been trickier to spot. The star described by the ancient Greek astronomer Ptolemy and named by medieval Islamic astronomers has started to fade from view. A notice posted in December by astronomer Edward Guinan at Villanova University described it as about half as bright as it was in September. Subsequent measurements by the same team have shown it has rapidly become the faintest, dimmest and reddest it has been in at least 40 years. It was off their charts.

"We changed the graph scale because I was plotting points in open space," says Guinan. However, any reports of Betelgeuse's demise are much exaggerated… or at least premature. One thing we know for certain about this supergiant star is that it won't be going out with a whimper. In fact, our models of stellar evolution show it will end its life in a huge supernova that is due anytime in the next 100,000 years. And some have speculated Betelgeuse's winter retreat might actually be preparation for an imminent grand finale.

When Betelgeuse does go supernova, whoever is around to see it will witness one of the greatest astronomical events of that decade, century and perhaps even millennium. If human civilisation is still going, the star will write its name in our astronomical history in a way that only a few others have. One example can be found in ancient Chinese manuscripts. These describe the appearance of a 'guest star' in the year 1054, an event since linked to the supernova that formed the famous Crab Nebula. Its appearance as a new light in the night sky, six-times brighter than Venus, was also noted in the Arab world, and more controversially has been linked to cave art in North America.



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Fast forward 500 years and stargazers found themselves in a golden era. Tycho Brahe studied a supernova in 1572, and Johannes Kepler witnessed the last supernova seen within our own galaxy in 1604. "Two in 32 years and then none seen by humans for the next 400 years? It's not fair," says Saurabh Jha, a supernova physicist at Rutgers University, who also missed the closest thing we know of since, back in 1987.

Guinan was more fortunate. In the spring of that year he was on a cruise ship just off Argentina, giving astronomy talks. The light from an exploding star in the Large Magellanic Cloud, which orbits the Milky Way, began to reach Earth, and hit the headlines. While it was a challenge to see it with the naked eye from built-up urban areas, it was clearly visible in the dark skies over the southern Atlantic. Guinan was compelled to act. "I had to make up talks quickly so I could take people out on deck and look at it."

To assess if Betelgeuse will add 2020 to the list of famous supernova years, we first need to understand their origin, and which stars produce them. While there are many types and subtypes, we can broadly divide these explosive events into two groups. Core collapse, or Type II supernovae, describe the final swansong of massive stars like Betelgeuse. These supergiants live fast and die young. They spend their 5 to 10 million years holding off the urge to collapse under their own massive gravity through rapid nuclear burning of their hydrogen fuel reserves. During their later life, once the hydrogen has been used up, increasingly larger elements are fused instead to balance the inward pressure. This act of resistance holds until the star's core is composed of iron. The element's refusal to fuse means gravity finally wins out. The outer layers then rapidly collapse inwards, producing a rebounding shock wave. This blows the whole atmospheric envelope off the star in a spectacular supernova.

The other main category is Type Ia supernovae, also called thermonuclear supernovae. These occur when a white dwarf star, like the one our Sun will leave behind after it dies, is found in a binary pair. If the white dwarf is able to accrete matter from its companion, this extra mass will compress its core, triggering collapse and a supernova. While much rarer than core-collapse events, which go off roughly every 50 years in our galaxy, thermonuclear supernovae are brighter and can therefore be seen from further away.

Despite all we have observed and learned about these supergiant stars, scientists cannot say for sure when Betelgeuse will become the next supernova event, only that it will. And it is highly debatable whether the recent dimming makes 2020 any more likely than 3030, 9090 or the year 20020. One reason for doubt, says Elizabeth Stanway, an associate professor of astronomy at the University

Above: Ancient Chinese manuscripts describe the supernova that formed the Crab Nebula as a 'guest star'

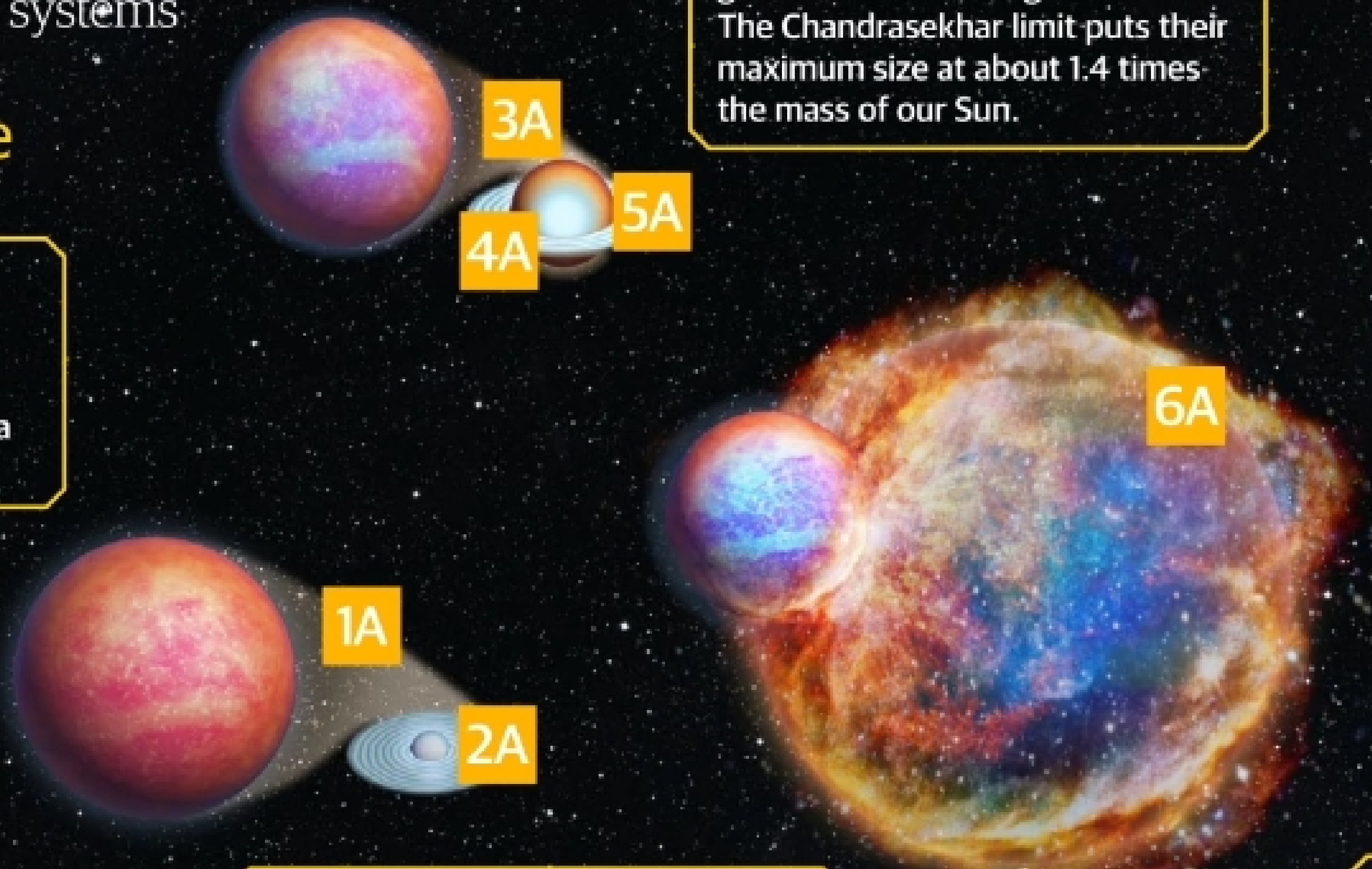
Right: The GOTO project, run by the University of Warwick, looks for the gravitational waves that accompany supernovae

© Antonio González / IAC

HOW DO STARS EXPLODE?

Stunning supernovae explosions can come from very different stellar systems

Type Ia supernovae



1A Matter transfer

Occasionally the two stars will orbit close enough to each other that matter will transfer from the companion onto the white dwarf star in a process called accretion.

2A Finding the right stars

These occur when a white dwarf, like the one our Sun will leave behind after its death, is found in a binary pair with another star.

3A Squeezing down

This accretion of matter from its companion adds extra mass. The additional gravitational forces compress the already highly pressurised core of the white dwarf.

4A A star reborn

As the star approaches the Chandrasekhar limit, the dying star comes to life again and undergoes fusion in its centre.

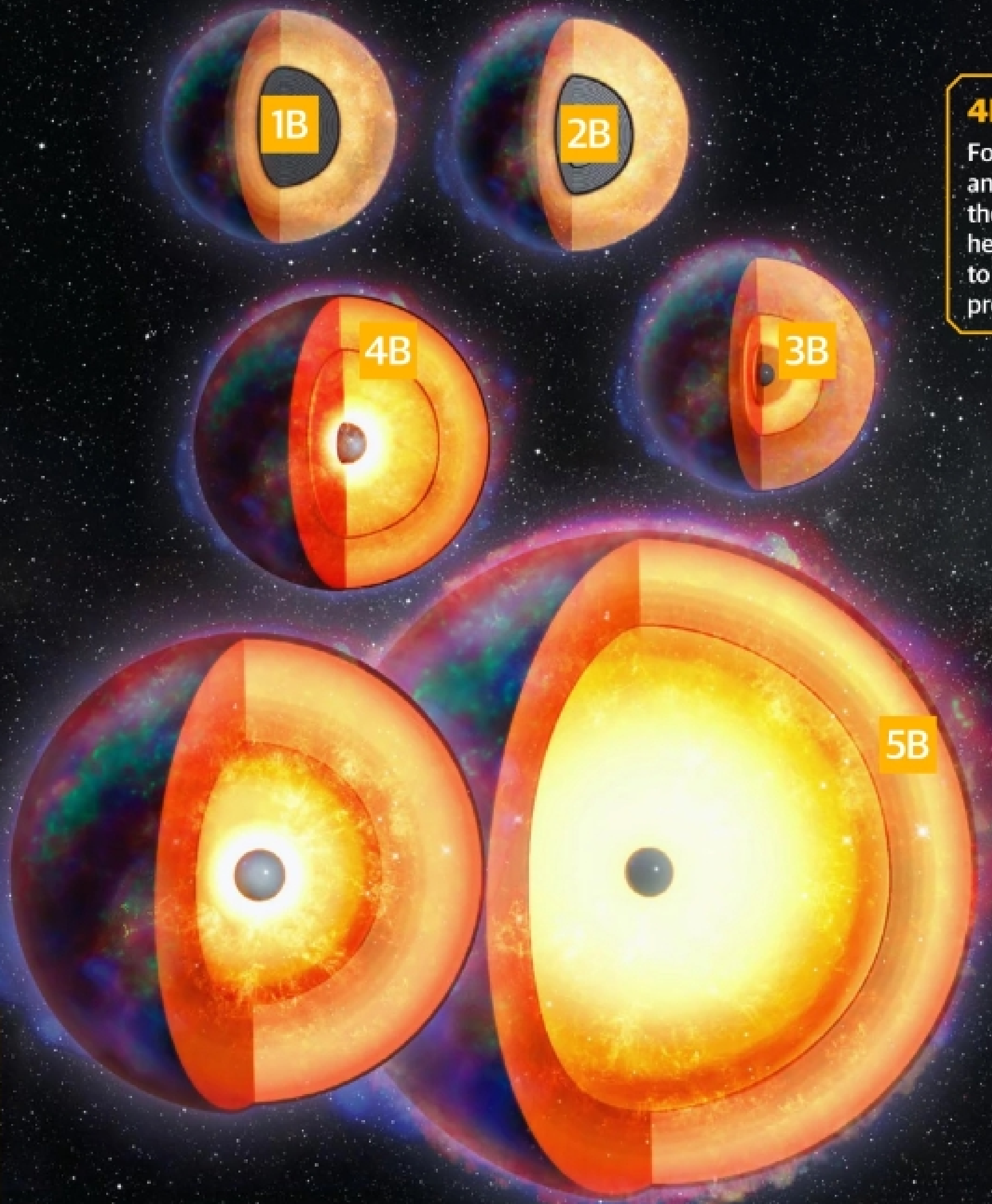
5A Limited gains

However, white dwarfs can only get so massive through accretion. The Chandrasekhar limit puts their maximum size at about 1.4 times the mass of our Sun.

6A Outward pressure

This time the star cannot expand to accommodate the outward pressure of its newly kindled fusion burning. Instead expansive forces build, eventually creating a violent supernova.

Type II supernovae



1B Out of gas

Supergiants like Betelgeuse will eventually run out of hydrogen and helium fuel, the nuclear burning of which prevents them collapsing in on themselves.

2B An elemental onion

Gradually heavier elements build up at the star's centre, which becomes layered like an onion, with lighter elements towards the outside of the star.

3B Resistance is futile

This act of resistance holds until the star's innermost core is composed of iron, which refuses to fuse. Gravity finally wins out and the star's outer layers collapse inwards.

4B Burning fuels

For stars this size, their mass and compressional forces at their core allow them to fuse heavier elements in order to maintain the outward pressure that holds off gravity.

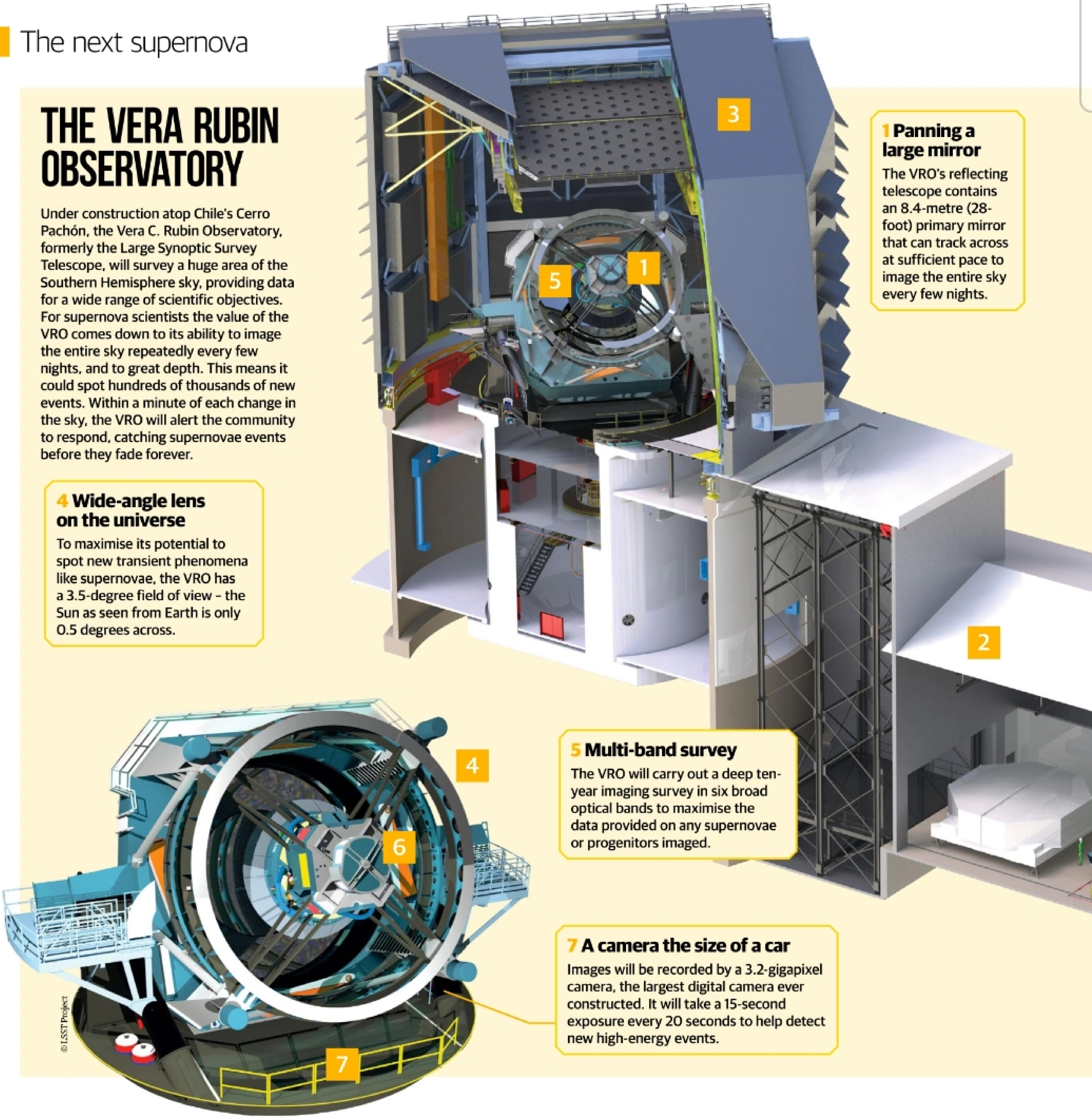
5B Shock wave rebound

This inward implosion bounces back off the core as a rebounding shock wave that blows the whole atmospheric envelope off the star, creating the spectacular supernova.

© Nicholas Forder

THE VERA RUBIN OBSERVATORY

Under construction atop Chile's Cerro Pachón, the Vera C. Rubin Observatory, formerly the Large Synoptic Survey Telescope, will survey a huge area of the Southern Hemisphere sky, providing data for a wide range of scientific objectives. For supernova scientists the value of the VRO comes down to its ability to image the entire sky repeatedly every few nights, and to great depth. This means it could spot hundreds of thousands of new events. Within a minute of each change in the sky, the VRO will alert the community to respond, catching supernovae events before they fade forever.



© LSST Project

1 Panning a large mirror

The VRO's reflecting telescope contains an 8.4-metre (28-foot) primary mirror that can track across at sufficient pace to image the entire sky every few nights.

4 Wide-angle lens on the universe

To maximise its potential to spot new transient phenomena like supernovae, the VRO has a 3.5-degree field of view – the Sun as seen from Earth is only 0.5 degrees across.

5 Multi-band survey

The VRO will carry out a deep ten-year imaging survey in six broad optical bands to maximise the data provided on any supernovae or progenitors imaged.

7 A camera the size of a car

Images will be recorded by a 3.2-gigapixel camera, the largest digital camera ever constructed. It will take a 15-second exposure every 20 seconds to help detect new high-energy events.

of Warwick, is that this changeable behaviour is not out of the ordinary for supergiant stars with bubbling, cauldron-like surfaces. "Betelgeuse has huge convection cells which produce sunspots that could eat our own Sun whole. It's fairly likely that the dimming just means it has more sunspots than normal." Guinan generally agrees – especially as the decline in brightness appears to be bottoming out – though he also understands the renewed interest in the star. "It's an unstable star. But it's doing something that it has never done in the last 150 years."

Doubts over the immediacy of Betelgeuse's big exit leave the door open for a wider community of so-called supergiant progenitor stars to step in and make their mark on our night skies. Antares, the red eye of the constellation of Scorpius, is a little bit closer to us than Betelgeuse, and at a similar stage in its life. Mu Cephei is further away, but at double the diameter of Betelgeuse may be closer to providing a 'guest star' akin to Venus in our dawn and dusk skies.

Further afield, Stanway points to Eta Carinae, a binary star, which observers have witnessed throwing out its outer layers in 1837, 1887 and 1998. Eta Carinae might be one of those rare stars which could produce a gamma-ray burst or superluminous supernova, though its distance poses no threat to Earth. "They are all on the launchpad. They are all unstable," says Guinan, whose hedging is evidence of the limitations science faces making any bolder supernovae predictions.

"In some situations our simulations provide the only insight of what the inside of a massive star may look like in the moments before its core collapses," says Carl E. Fields, an astronomy PhD

HOW BETELGEUSE'S SUPERNOVA WILL LOOK FROM EARTH

Getting brighter

Between now and 100,000 years' time

Astronomers will know Betelgeuse has exploded before we see it. The light of the explosion will be slowed down as it passes through gas surrounding the dying star. Ghostly particles called neutrinos will pass straight through and beat the light here.

At its brightest

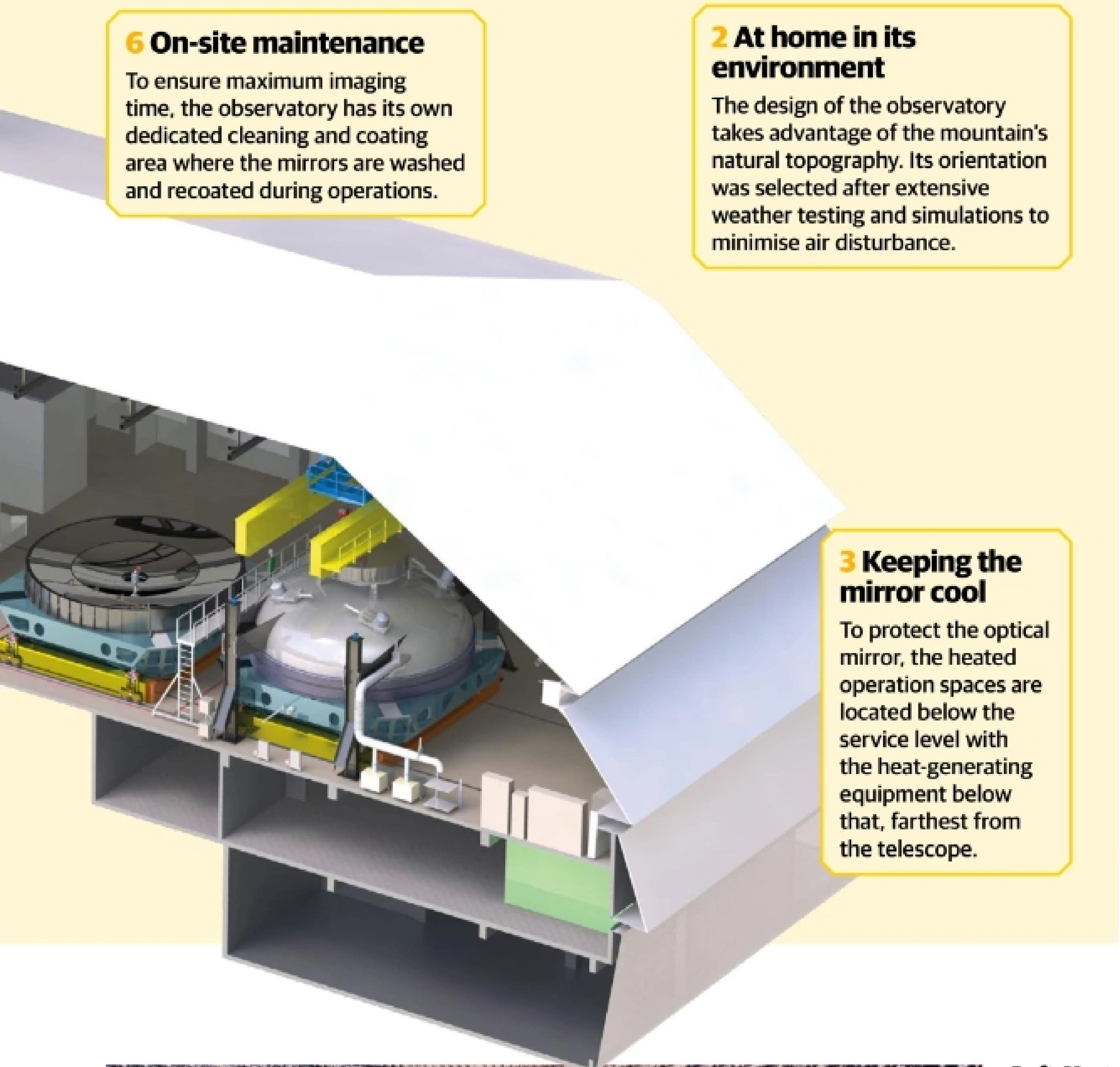
First week of brightening

Betelgeuse will take time to ramp up to maximum brightness – this usually takes about a week or two. Astronomers can estimate this by looking at how the light from other similar supernovae varies in the days and weeks after denotation.

Fading away

A few months after peak brightness

The light curves from other Type II supernovae show that the fading process happens in two stages. First it drops in brightness by a factor of ten over a couple of weeks, then its brightness plateaus for a month or two before tailing off further.



6 On-site maintenance

To ensure maximum imaging time, the observatory has its own dedicated cleaning and coating area where the mirrors are washed and recoated during operations.

2 At home in its environment

The design of the observatory takes advantage of the mountain's natural topography. Its orientation was selected after extensive weather testing and simulations to minimise air disturbance.

3 Keeping the mirror cool

To protect the optical mirror, the heated operation spaces are located below the service level with the heat-generating equipment below that, farthest from the telescope.

Source: Wikipedia © LSST Project/J. Andrew

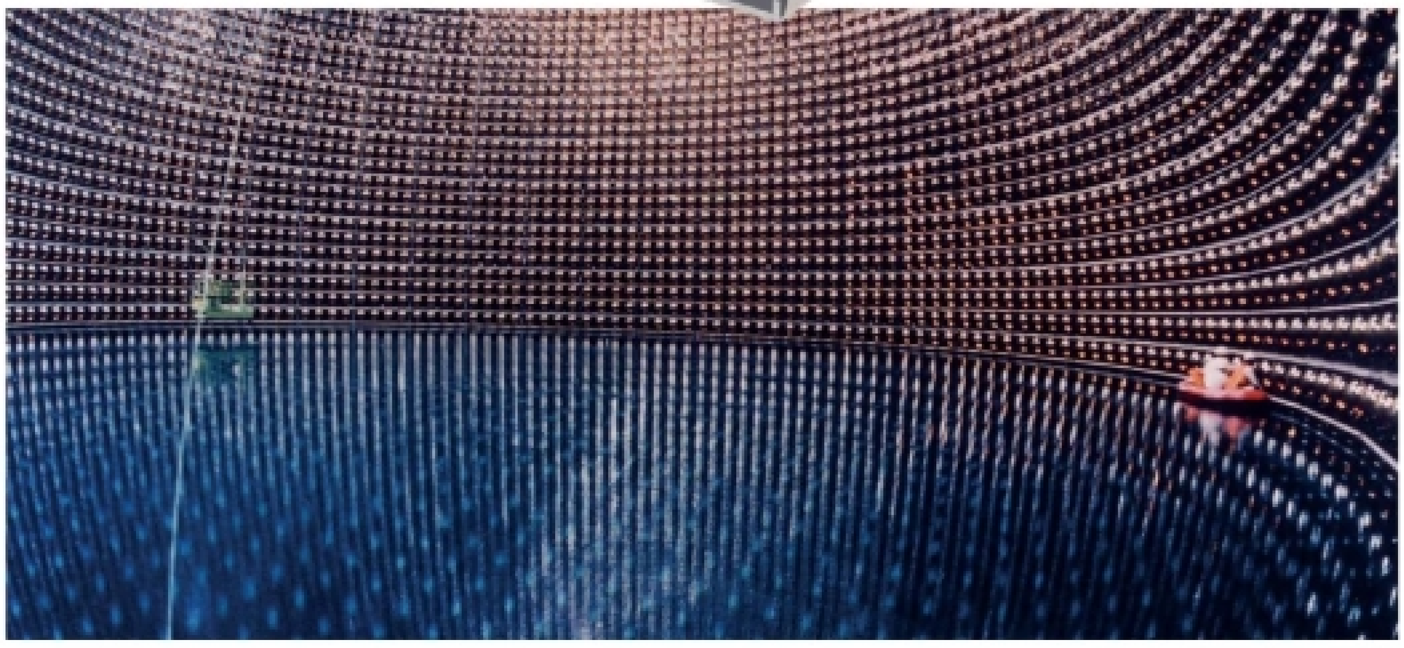
student developing these models at Michigan State University. This is because a lot of the important physics that happens in the final stages of a star's life takes place deep within its core. And it takes days, weeks or even years for any evidence to affect the surface. "By contrast, the shock wave of a supernova can blast its way out of the star very rapidly, so will overtake most of the indications we'd be looking for," says Stanway.

Uncertainty hasn't stopped speculation. Guinan recently returned from the American Astronomical Society meeting in Hawaii. Many delegates wanted to speak to him about his notices on Betelgeuse and what they thought you might see if it was about to go supernova. "Some of them thought nothing. It would just happen. And then there were a few that thought there would be dimming, and then six months later it would take off."

In the meantime, teams continue searching for 'warning signs', looking back through old observation plates to find stellar sources of later-observed supernovae. However, because these events come out of the blue, there is never an opportunity to organise detailed surveys in the lead up. This leaves astronomers with at best a single image, which alone cannot reveal unusual variability or behaviour.

Others are looking outside optical light for clues. Type II supernovae are accompanied by huge amounts of 'ghostly' non-interacting neutrino particles that can pass seamlessly outwards through the star's atmosphere. These are flung into space long before we expect anything to have changed on the star's surface, as the light struggles to make its way out of these giant stars. When supernova 1987a exploded, Earth-based instruments detected a small spike of a dozen or so neutrinos. Betelgeuse is so near you could get 20,000 or 30,000 neutrino detections, says Guinan.

"We might start detecting neutrinos weeks or even months before the supernova explosion, and

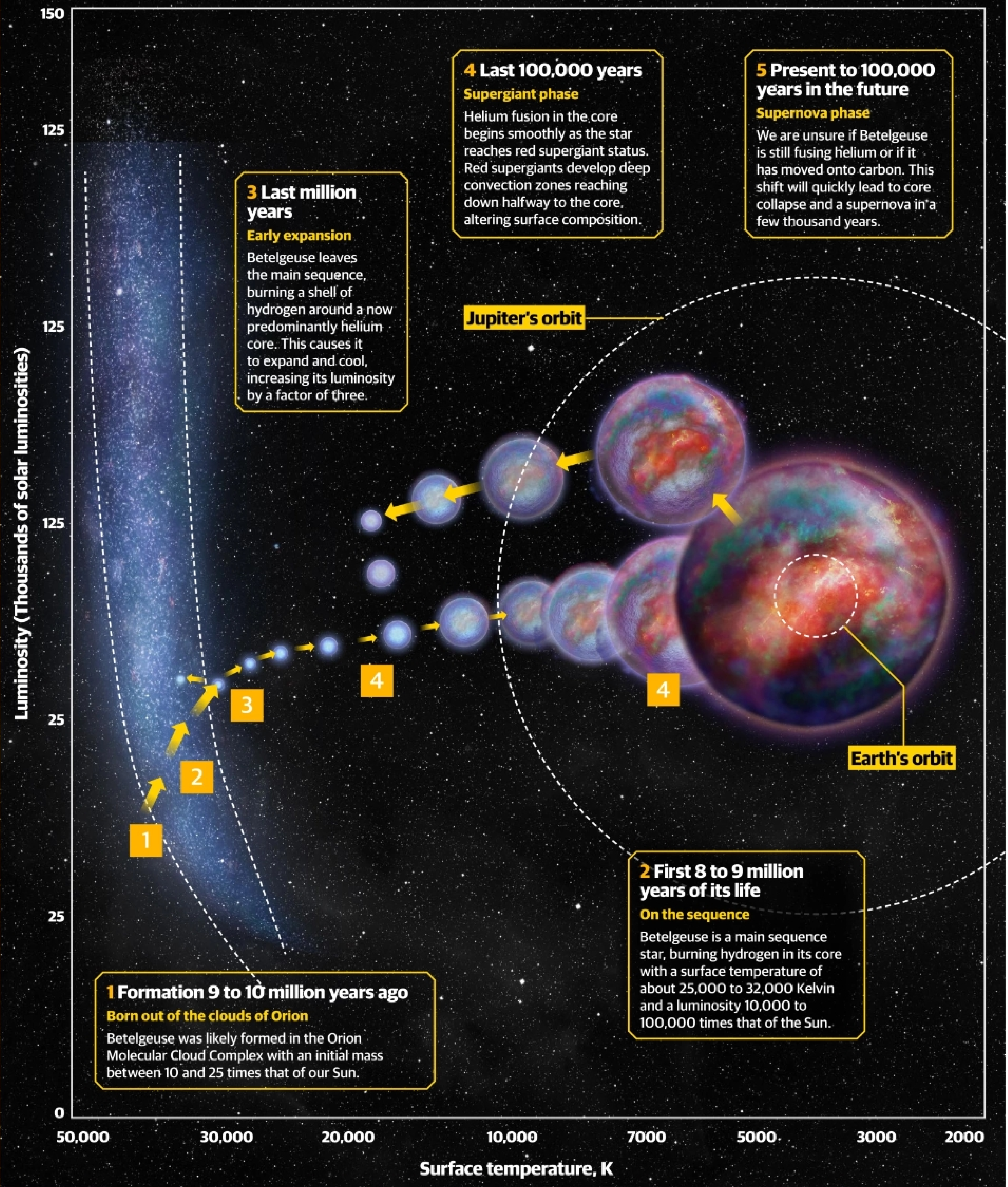


Left: Neutrino detectors like the Super-Kamiokande in Japan could spot early signs of a nearby supernova

© Kamioka Observatory, ICRR, University of Tokyo

GOING SUPERNOVA

Our knowledge of Betelgeuse and star evolution allow us to map its life and predict its death



1 Formation 9 to 10 million years ago

Born out of the clouds of Orion

Betelgeuse was likely formed in the Orion Molecular Cloud Complex with an initial mass between 10 and 25 times that of our Sun.

2 First 8 to 9 million years of its life

On the sequence

Betelgeuse is a main sequence star, burning hydrogen in its core with a surface temperature of about 25,000 to 32,000 Kelvin and a luminosity 10,000 to 100,000 times that of the Sun.

3 Last million years

Early expansion

Betelgeuse leaves the main sequence, burning a shell of hydrogen around a now predominantly helium core. This causes it to expand and cool, increasing its luminosity by a factor of three.

4 Last 100,000 years

Supergiant phase

Helium fusion in the core begins smoothly as the star reaches red supergiant status. Red supergiants develop deep convection zones reaching down halfway to the core, altering surface composition.

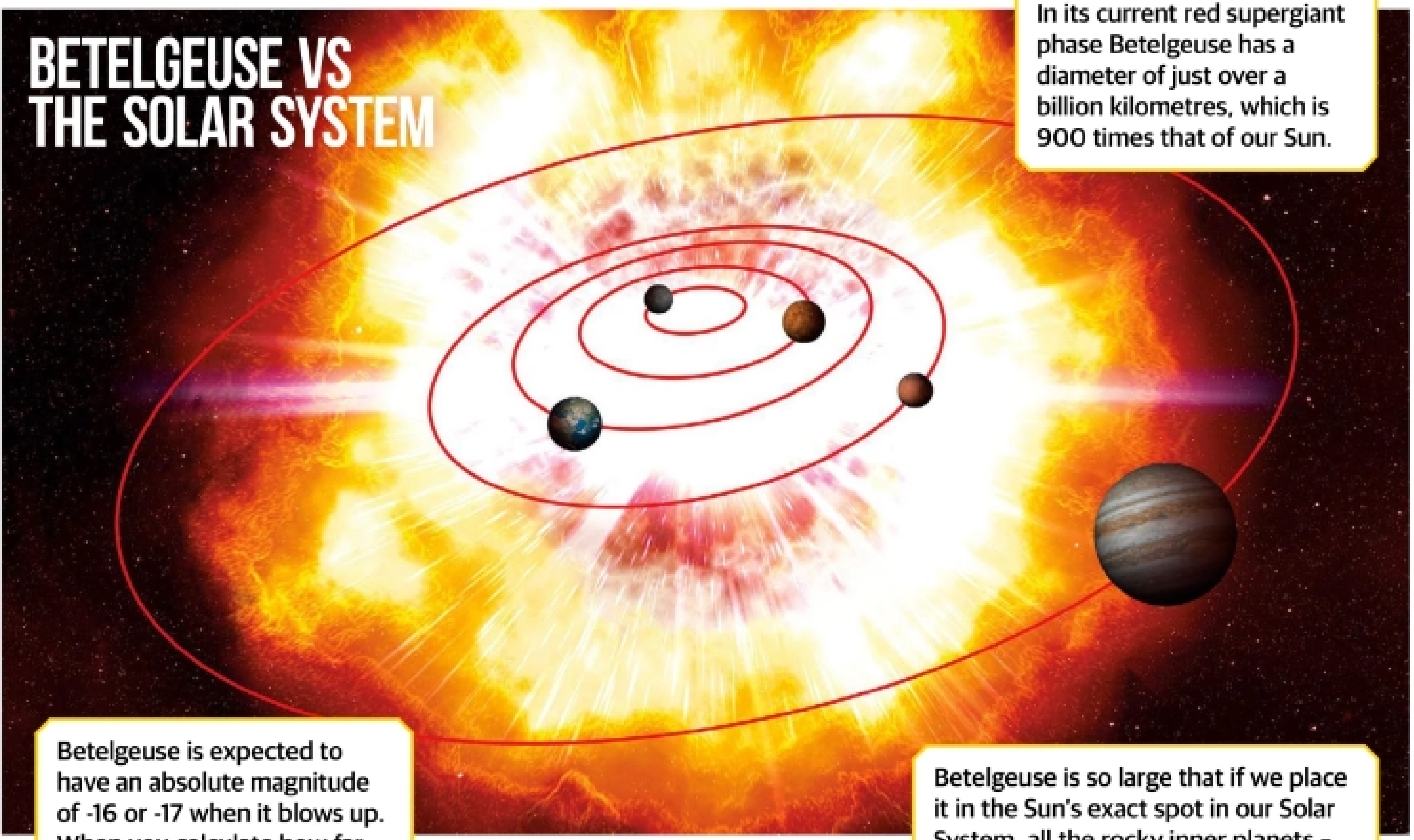
5 Present to 100,000 years in the future

Supernova phase

We are unsure if Betelgeuse is still fusing helium or if it has moved onto carbon. This shift will quickly lead to core collapse and a supernova in a few thousand years.

© Nicholas Forder

BETELGEUSE VS THE SOLAR SYSTEM



In its current red supergiant phase Betelgeuse has a diameter of just over a billion kilometres, which is 900 times that of our Sun.

Betelgeuse is expected to have an absolute magnitude of -16 or -17 when it blows up. When you calculate how far away it is, this would make it as bright as the full Moon.

Betelgeuse is so large that if we place it in the Sun's exact spot in our Solar System, all the rocky inner planets – and perhaps even Jupiter – would be orbiting inside its atmosphere.

© Getty

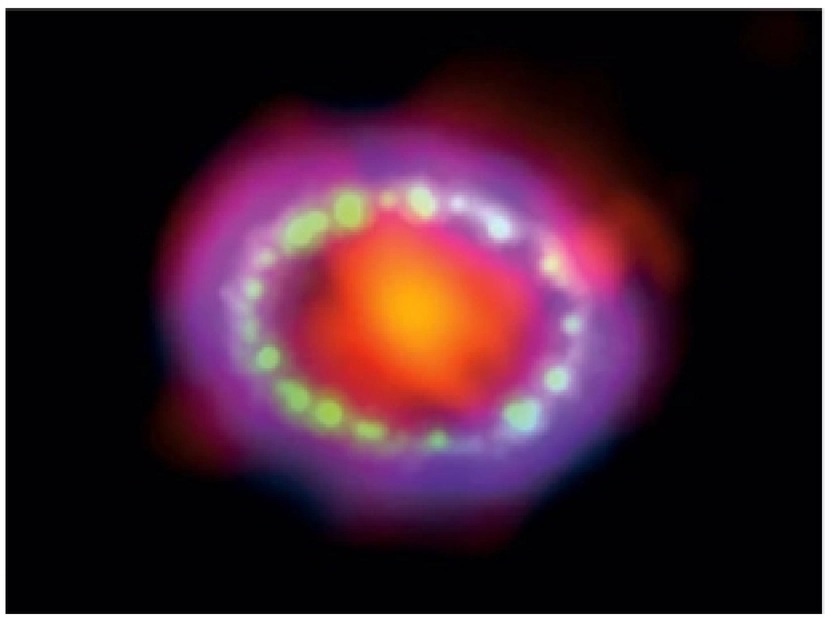
the rate would keep increasing until the explosion," says Jha. However, as the next generation of neutrino detectors are being built, research into the plausibility of a neutrino-based supernovae early warning system has thrown up some challenges, says Fields. "If an event is detected in a single detector, little to no information about its origin will be included in the signal." While pre-supernovae physics might have to rely on simulations for a while longer, the observational data we will get from the next nearby supernova will keep scientists busy for years and decades to come. It will be a tantalising wait.

Wide-field arrays such as the All-Sky Automated Survey for Supernovae, featuring a global network of 20 robotic telescopes, could help pinpoint the source, and may even spot the first hints of surface change. In other wavelengths you have surveys capturing high-energy cosmic rays such as IceCube, while space telescopes like Fermi, Integral and Swift can record events in X-rays and gamma rays. All of these are already contributing significantly to a rapidly growing record of supernovae events further afield. In the first three weeks of 2020 the Transient Name Server, where the astronomy community logs their observations, added 983 new events, of which 68 have been confirmed as supernovae.

At Stanway's University of Warwick, the Gravitational-wave Optical Transient Observer project is looking out for gravitational waves that accompany large supernovae events. In January Betelgeuse hit the headlines for a second time after the detection of exactly this type of wave, coming from the direction of Orion. The link has since been dismissed, but it's exactly what's expected if the red supergiant enters its final phase. "It got me scared," says Guinan, who admits to immediately running outside to check on the star.

So where will the next supernovae take place? On a universal scale, several will have gone off across the cosmos by the time you finish this sentence. In terms of our immediate galactic neighbourhood, several new events are confirmed each day, though it's very unlikely the next one, or even the next few dozen, will make ripples beyond the astronomy community. "The most likely scenario is that the next nearby event will come from an obscure star which doesn't even have a name outside of scientific catalogues," says Stanway.

If we are talking about the next supernova that will light up our night skies and stop people in the street, then Betelgeuse and the progenitors monitored by Guinan are certainly good bets. He, for one, is keeping fingers crossed. "It could be tonight. It could be a hundred thousand years from now. I would prefer it to be now. I'm getting old. It would be great to see it."



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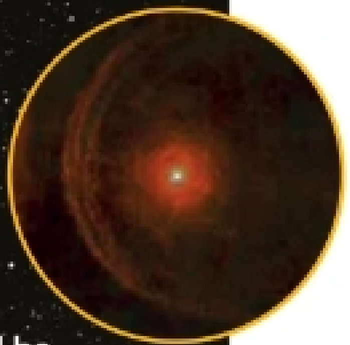
Bottom left: Supernova 1987a was the last supernova that was visible to the naked eye

FIVE STARS READY TO EXPLODE

Betelgeuse



© ESA

Stellar evolution models suggest it should go supernova anytime in the next 100,000 years, when it will be as bright as the full Moon in the night sky. Even before its recent dimming Betelgeuse showed the most variation of any progenitors.

Antares

© ESO

The red eye of the scorpion in the constellation Scorpius is due to go supernova in the next million years. With a mass 15 to 18 times that of our Sun, it will be spectacular, though its lack of variability suggests it's not quite ready yet.

Mu Cephei

© ESA

Known as 'Herschel's Garnet', it's further away than Betelgeuse, but double its diameter, and therefore perhaps closer to death. Its supernova would likely produce a black hole while providing a 'guest star' as bright as Venus.

Eta Carinae

© NASA/ESA

Observers have already seen this binary star throw out its outermost layers in a series of pulses. Much further away than Betelgeuse, its impending death could produce a gamma-ray burst or a superluminous supernova, easily visible from Earth.

V Sagittae

© NASA

Made up of an ordinary star spiralling in towards a white dwarf, researchers have predicted a date later in this century for a supernova event that will create a 'new star' as bright as Sirius in the night sky.

MISSION PROFILE

OSIRIS-REx

NASA's asteroid explorer has been at Bennu for over a year now, but the best part is yet to come

Mission type
Sample return
Operator
NASA
Launch date
8 September 2016
Target
101955 Bennu
Arrival at target
3 December 2018
Primary objective
Survey and collect a sample from a carbon-rich near-Earth asteroid
Status
Operational

© Symeon Platts/UA

Professor Dante Lauretta
Principal investigator of the OSIRIS-REx mission
Lauretta is a professor of planetary science and cosmochemistry at the University of Arizona's Lunar and Planetary Laboratory in Tucson, Arizona. He specialises in near-Earth asteroid formation and evolution.

OSIRIS-REx is the third part of NASA's New Frontiers Program, succeeding the likes of New Horizons and Juno. All three are completely reshaping our understanding of the Solar System, and OSIRIS-REx is doing so at the asteroid 101955 Bennu.

The Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) spacecraft was launched with a game plan to break records and do something that hasn't been done since the Apollo era. "It's a mission to reach out to a near-Earth asteroid named Bennu and survey that object in great detail, ultimately selecting a single location on the asteroid surface to send the spacecraft down for a brief contact to collect material that we will return to Earth for analysis in our laboratories," explains Lauretta.

When the spacecraft sends its return capsule to Earth from Bennu in September 2023, carrying at the very least 60 grams (2.1 ounces) of asteroid regolith, it will deliver a sample from space in a quantity that hasn't been seen since the Apollo astronauts returned lunar samples in the 1960s and 1970s. But what makes Bennu so special?

First is that Bennu is a near-Earth asteroid, and being in close proximity to Earth means the spacecraft doesn't have to journey to the outskirts of the Solar System to sample it. Secondly, the asteroid is small enough – with a diameter of roughly 500 metres (1,600 feet) – and rotates slowly enough that it enables OSIRIS-REx to enter its orbit and conduct close-up observations without orbital complications. Thirdly, Bennu is a rare B-type carbon-rich asteroid that astronomers believe could hold clues about the Solar System's inception. Bennu can be thought of as a frozen time capsule, left over from the formation of the planets.

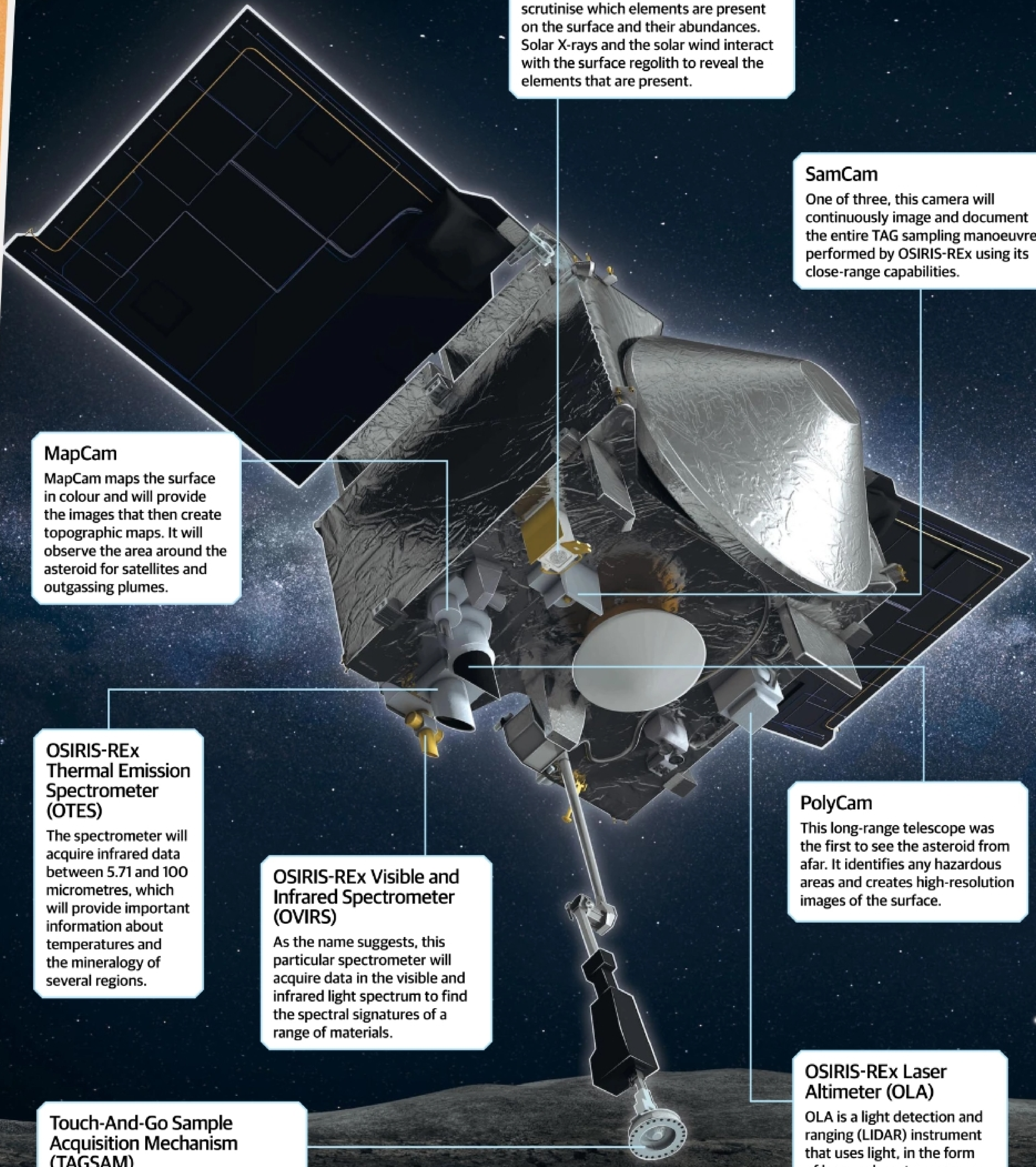
"We chose Bennu specifically because we knew a lot about it and intriguing hints about its composition," says Laurette. "We think Bennu may have water in the form of clay minerals and organic molecules that we think may have represented the seeds for the origin of life on Earth."

4.5 billion years ago, asteroids, comets and other pieces of space rock began to accumulate until they formed the planets and dwarf planets that are seen today. In the process, some of these planets acquired liquid water on the surface, such as Earth and Mars, and Earth was even blessed with organic compounds that provided the building blocks for human life. Scientists believe that asteroids such as Bennu are the key to understanding how chemistry created biology. "OSIRIS-REx really seeks to answer some of the most fundamental questions that we ask ourselves," says Laurette. "It's a great example of what humanity can accomplish when a talented group of dedicated people put their minds on a single objective."

This sample-return mission has another goal in understanding the current nature of near-Earth asteroids. When it comes to around-the-clock asteroid observations, modern techniques have brought to light just how hazardous these objects can be. By scrutinising Bennu, the mission could provide vigilant astronomers with important information about a future Earth-bound asteroid. Not only that, but asteroids could soon become utilised in space mining. Companies could soon be sending mining missions to asteroids to extract their rare resources, and OSIRIS-REx can provide a more complete understanding of what resources might be hidden within.

OSIRIS-REx arrived at Bennu on 3 December 2018, beginning an in-depth survey of the entire surface, mapping from pole to pole. While doing so it has been slowly decreasing the altitude of its orbit, and it will continue until it hovers just 240 metres (800 feet) over the asteroid's surface. In July 2020 OSIRIS-REx will perform NASA's first-ever robotic sample collection of a celestial object using the Touch-And-Go (TAG) sampling manoeuvre. After collecting an adequate sample the spacecraft will depart from Bennu in March 2021, where it will cruise back to Earth and drop off an uncontaminated sample – fresh from the vacuum of space – in the Utah Desert in September 2023.

OSIRIS-REx's kit



© NASA/University of Arizona

Regolith X-ray Imaging Spectrometer (REXIS)

This is a student experiment that will scrutinise which elements are present on the surface and their abundances. Solar X-rays and the solar wind interact with the surface regolith to reveal the elements that are present.

SamCam

One of three, this camera will continuously image and document the entire TAG sampling manoeuvre performed by OSIRIS-REx using its close-range capabilities.

MapCam

MapCam maps the surface in colour and will provide the images that then create topographic maps. It will observe the area around the asteroid for satellites and outgassing plumes.

OSIRIS-REx Thermal Emission Spectrometer (OTES)

The spectrometer will acquire infrared data between 5.71 and 100 micrometres, which will provide important information about temperatures and the mineralogy of several regions.

OSIRIS-REx Visible and Infrared Spectrometer (OVIRS)

As the name suggests, this particular spectrometer will acquire data in the visible and infrared light spectrum to find the spectral signatures of a range of materials.

PolyCam

This long-range telescope was the first to see the asteroid from afar. It identifies any hazardous areas and creates high-resolution images of the surface.

OSIRIS-REx Laser Altimeter (OLA)

OLA is a light detection and ranging (LIDAR) instrument that uses light, in the form of laser pulses, to measure distances. This provides high-resolution topographic data of the surface of Bennu.

Touch-And-Go Sample Acquisition Mechanism (TAGSAM)

The sampler head and arm will retrieve the surface sample that astronomers are eagerly awaiting. TAGSAM has three separate bottles of gas which will allow up to three attempts of collecting a sample.

MISSION PROFILE

Progress report

Since OSIRIS-REx arrived at Bennu, it's spent the best part of a year surveying the asteroid, revealing new mysteries and pinpointing the perfect location to prop itself down to extract a surface sample. On 12 December 2019 the OSIRIS-REx team announced that the site for their sample collection will be a region near the north pole, nicknamed Nightingale. "This is a day I've been dreaming of for over a decade," says Lauretta. "And it's the culmination of the work of hundreds of people working thousands of hours poring over the data that we've returned from the asteroid over the past year."

Nightingale was chosen ahead of the other sites – Kingfisher, Osprey and Sandpiper – as it showed it has lots of finely grained material, which makes it easy to collect. The region also has a lower albedo, which could be an indication of the presence of organic material.

In other news, astronomers have been trying to work out the mystery of the asteroid ejecting particles into space. When the spacecraft first arrived, these particles could have been easily confused with stars in the background. However, after further investigation it was discovered that the asteroid is emitting material for some unknown reason. Three likely explanations are that it is the result of impacts with meteoroids, thermal stress fracturing or the release of water vapour.

"Among Bennu's many surprises, the particle ejections sparked our curiosity, and we've spent the last several months investigating this mystery," explains Lauretta. "This is a great opportunity to expand our knowledge of how asteroids behave."

The team have stated that any of these three explanations are plausible, or it could even be a combination of them. They are also hoping that a sample of this emitted material will find its way into the sampling mechanism of OSIRIS-REx, meaning that there could be an answer waiting for them come 2023.

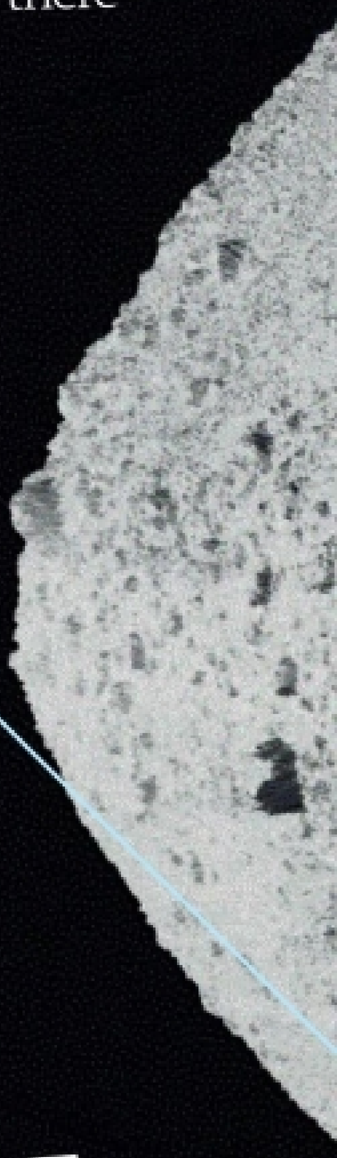
OSIRIS-REx is equipped with cameras, spectrometers and a sophisticated sample-collecting mechanical arm

© NASA

> "OSIRIS-REx really seeks to answer some of the most fundamental questions that we ask ourselves" **Dante Lauretta**

The four sampling sites on Bennu

These sites, named after birds native to Egypt, were the four candidates singled out to be visited by OSIRIS-REx. But there can only be one...



Sandpiper

Latitude: -47 degrees

Longitude: 322 degrees

The southernmost site is a flat piece of land on the wall of a large crater, but appears to have hydrated minerals. This could have revealed promising details about unmodified water-rich materials.

To Bennu and back

Launch from Earth

September 2016

OSIRIS-REx endured a successful launch before beginning its two-year, 2-billion-kilometre (1.2-billion-mile) journey through space to asteroid Bennu, including a flyby of Earth.

© United Launch Alliance

Arrival at Bennu

December 2018

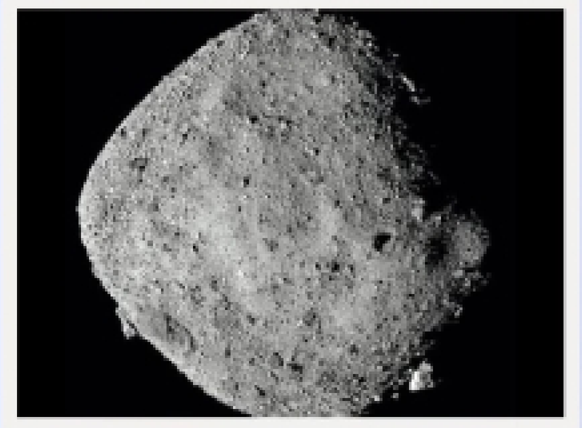
The approach phase began in August 2018, with about 2 million kilometres (1.2 million miles) separating the two, but the spacecraft didn't actually arrive at Bennu until December 2018.

© NASA/University of Arizona

Surveying the site

December 2018 – August 2019

OSIRIS-REx began surveying the asteroid, broken down into four different phases: 'During Preliminary Survey', 'In Orbital A', 'In Detailed Survey' and 'During Orbital B'.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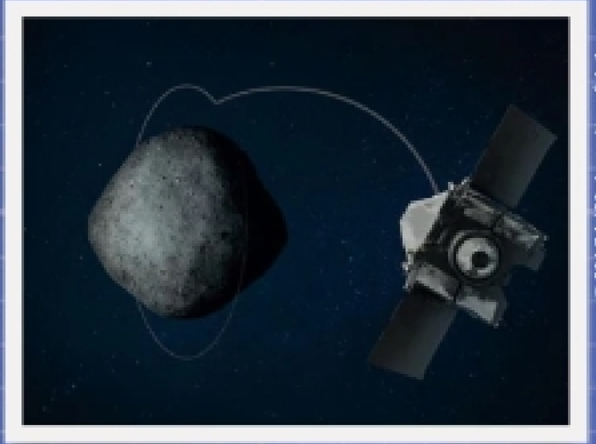
Sample rehearsal

April 2020 – June 2020

Prior to the main event, the spacecraft will undergo at least two sample collection rehearsals. It will leave its orbit, manoeuvre itself above its target and return to orbit.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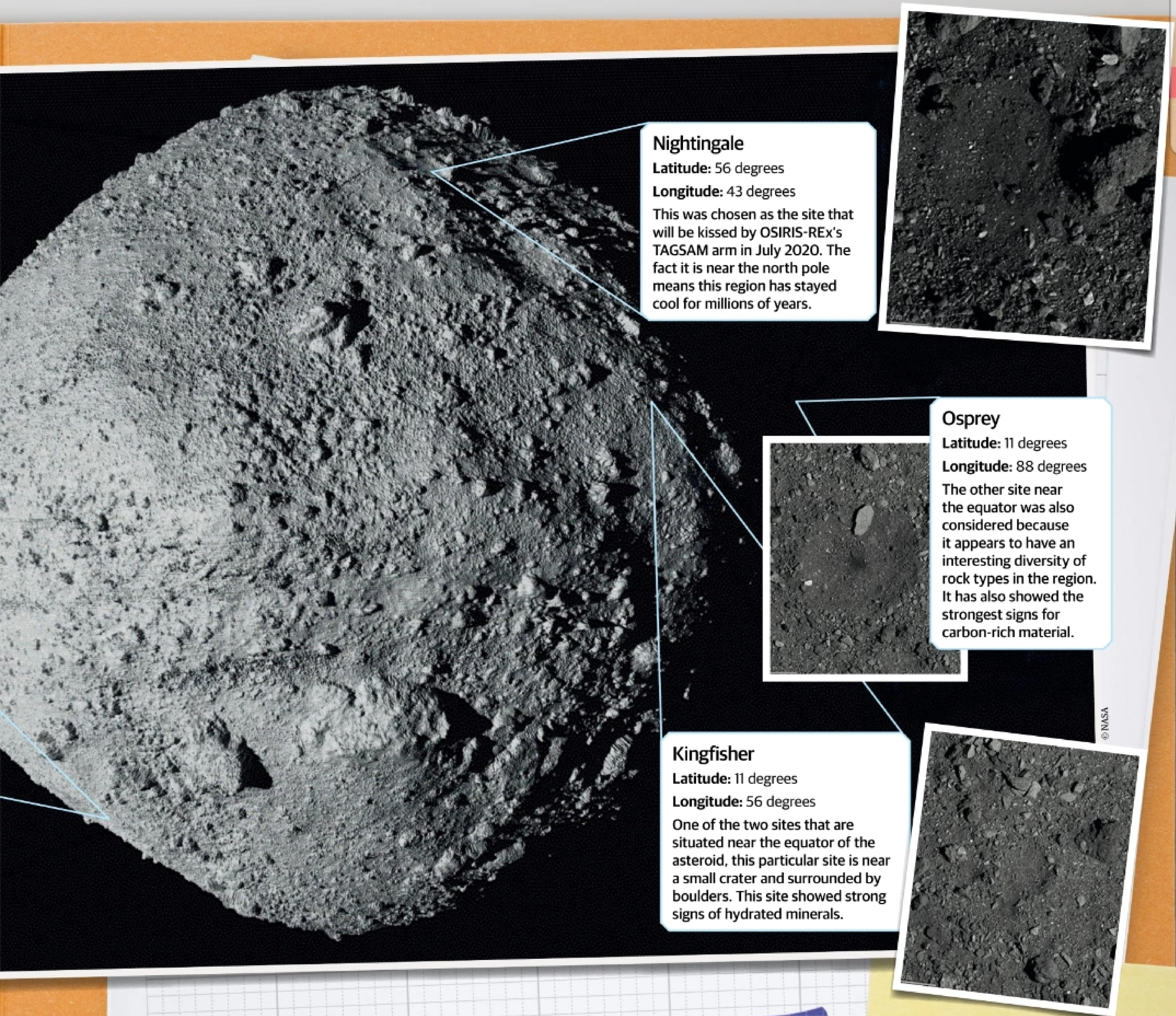


Nightingale

Latitude: 56 degrees

Longitude: 43 degrees

This was chosen as the site that will be kissed by OSIRIS-REx's TAGSAM arm in July 2020. The fact it is near the north pole means this region has stayed cool for millions of years.

Osprey

Latitude: 11 degrees

Longitude: 88 degrees

The other site near the equator was also considered because it appears to have an interesting diversity of rock types in the region. It has also showed the strongest signs for carbon-rich material.

Kingfisher

Latitude: 11 degrees

Longitude: 56 degrees

One of the two sites that are situated near the equator of the asteroid, this particular site is near a small crater and surrounded by boulders. This site showed strong signs of hydrated minerals.

© NASA

Touch and go

July 2020

The sampling head will touch the surface for five seconds. During this, a burst of nitrogen gas will kick up loose material, which will be collected and stored.

© NASA

Leaving the scene

March 2021

After the sample has been placed in the Sample Return Capsule (SRC), it will evacuate Bennu and begin its two-and-a-half year journey back to Earth.

© NASA/University of Arizona

Dropping off the goods

September 2023

Four hours before reaching Earth's atmosphere, the SRC will be jettisoned from the spacecraft, where it will eventually land somewhere in the Utah Desert.

© NASA

Main objectives

Searching for the origin of life

Return a sample of a carbon-rich asteroid that hasn't been contaminated by Earth entry and analyse the sample for signs of ancient water and organic compounds.

Probing Bennu's evolution

This mission will fully map the geology, mineralogy and surface properties of asteroid Bennu, which will hopefully reveal its geological history.

Understand the Yarkovsky effect

The Yarkovsky effect is the thermal force acting upon a rotating body in space, and in this case the rotating body is Bennu. This will help understand the behaviour of a potentially hazardous asteroid.

©Tobias Roetsch

MYSTERIES OF THE UNIVERSE

WHAT'S ORBITING OUR GALAXY'S BLACK HOLE?

Six strange objects have been found in the vicinity of Sagittarius A* - and there may be more

Reported by David Crookes

At the heart of the Milky Way is a supermassive black hole called Sagittarius A*. We know it is 26,000 light years from Earth and that it has 4 million times the mass of the Sun. We also found out last year that it is surrounded by a cool gas halo and is perhaps quieter than its counterparts in other galaxies because of magnetic fields.

What we're less certain about, however, is the make-up of six strange objects that have been discovered relatively close by. Found to orbit Sagittarius A*, or Sgr A* as it is also known, they are a few hundred astronomical units away from the galactic centre and take anywhere between 170 and 1,600 years to complete their circuit.

"These objects look like gas and behave like stars," says Andrea Ghez, a professor of physics and astronomy at UCLA, who co-authored a recent study into the objects. Yet the exact identification of what is said to be a new class of object is still being worked on, and teams coming up with potential theories appear to be split.

The objects began to truly puzzle astronomers after one of them, named G2, was seen to make a close approach to the supermassive black hole in 2014. It had originally been discovered in 2011 by a team based in Germany, and the expectation was that it would be ripped to shreds and cause a flash of radiation.

Instead it was observed becoming elongated, and while much of its gassy outer shell was torn apart, it survived and continued on its way, becoming more compact once again. "It went from being a pretty innocuous object when it was far from the black hole to one that was really stretched out and distorted at its closest approach," Ghez explains.

THE G OBJECTS BY THE NUMBERS

6
G objects that have been found so far

0.13
Number of light years from the black hole Sgr A*

15 BILLION
Size of the G objects in kilometres

That's 100 times the distance between the Earth and the Sun

170
Shortest orbital period of a G object in years

1,600
Longest orbital period of a G object in years

1974
Year Sagittarius A* was first discovered

2005
Year the first G object was first observed

4 MILLION SUNS
The immense mass of the black hole

26,000
Number of light years between Earth and Sgr A*

© ESO

Above: The objects may originate from binary stars forced to merge under the intense influence of Sgr A*

Right: When observing G2 on its approach to the cloud using the ESO's Very Large Telescope, astronomers were able to work out where on its orbit the different parts of the cloud were located

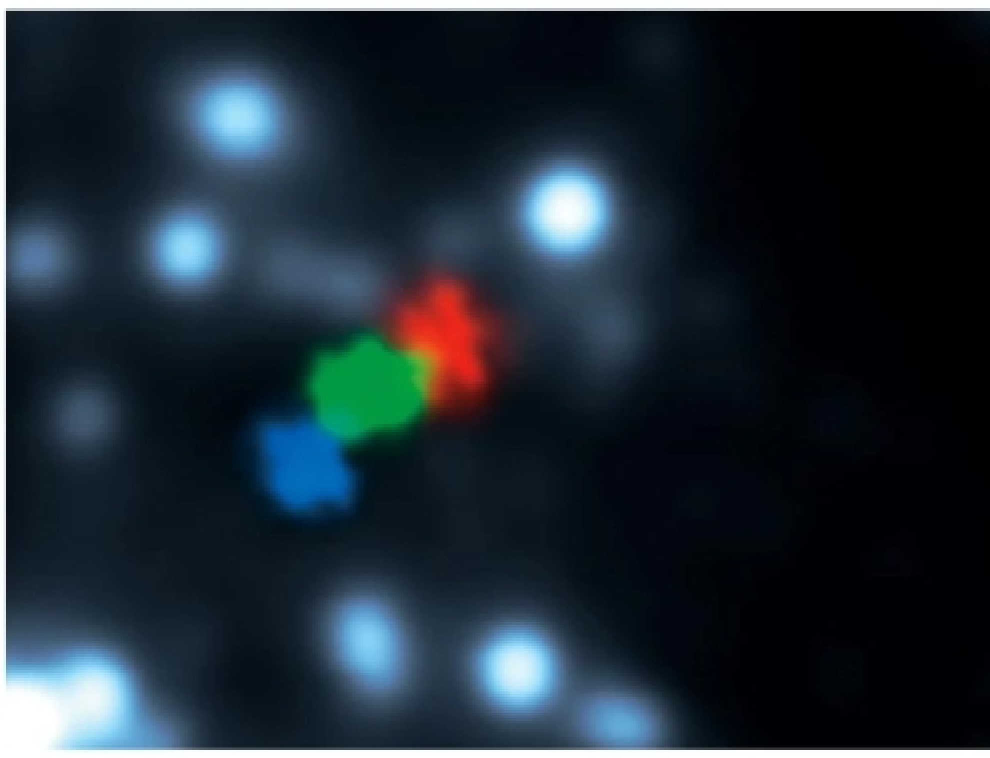
At this stage, G2 could have been treated as an outlier – a strange object behaving oddly alone. But some years earlier in 2005, astronomers had also discovered another strange object close to Sgr A*. In light of G2, this became known as G1, and it set Ghez wondering whether G1 and G2 could be part of a larger class of objects.

As such, together with her colleagues, Ghez subsequently went back over 13 years of data taken from observations from the W.M. Keck Observatory in Hawaii, and found evidence linking four more. These became known as G3, G4, G5 and G6, collectively known as the G objects. Certainly, they were looked upon by astronomers with great excitement. "Such objects had not been seen before in any other environment," says Mark Morris, a UCLA professor of physics and astronomy who worked with Ghez on the study.

"By stellar standards their dust photospheres are very cold, and because they are in a region with a strong background of ultraviolet radiation they are partially ionised and show up in emissions from very hot hydrogen atoms, which again hasn't been seen elsewhere. They also appear to be present only in the entourage of the black hole."

G3 through to G6 follow a different orbit to G1 and G2 around the supermassive black hole, which points to them having developed independently of each other, even though their behaviour in relation to Sgr A* was determined to be the same. "In every passage the tidal forces of the black hole can remove some of the material from the outer layers of some of the G objects," Morris says. "We actually observed that happening for both G1 and G2."

> **"THE TIDAL FORCES OF THE BLACK HOLE CAN REMOVE SOME OF THE MATERIAL FROM THE OUTER LAYERS OF SOME OF THE G OBJECTS"** MARK MORRIS



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He says there can be two main possible explanations for this. "I think they're either gas clouds or stars, which reflects the ongoing debate between the German group at the Max Planck Institute for Extraterrestrial Physics and ours at UCLA," he tells **All About Space**.

Morris says that his group are strong proponents of the hypothesis that the G objects are stars surrounded by a cocoon of dust and gas. "Can they be something else entirely?" he asks. "Yes, of course, but I think the realm of possibilities has been well scoured, so alternative hypotheses would need to be quite surprising and unexpected."

He certainly rejects the rival theory put forward by the German team that they are compact clouds of gas and dust because he says this would cause the objects to be torn apart. "They'd be tidally disrupted as they pass through the point of closest approach to the black hole, and yet two of the G objects have gone through their close approach and survived intact," he says.

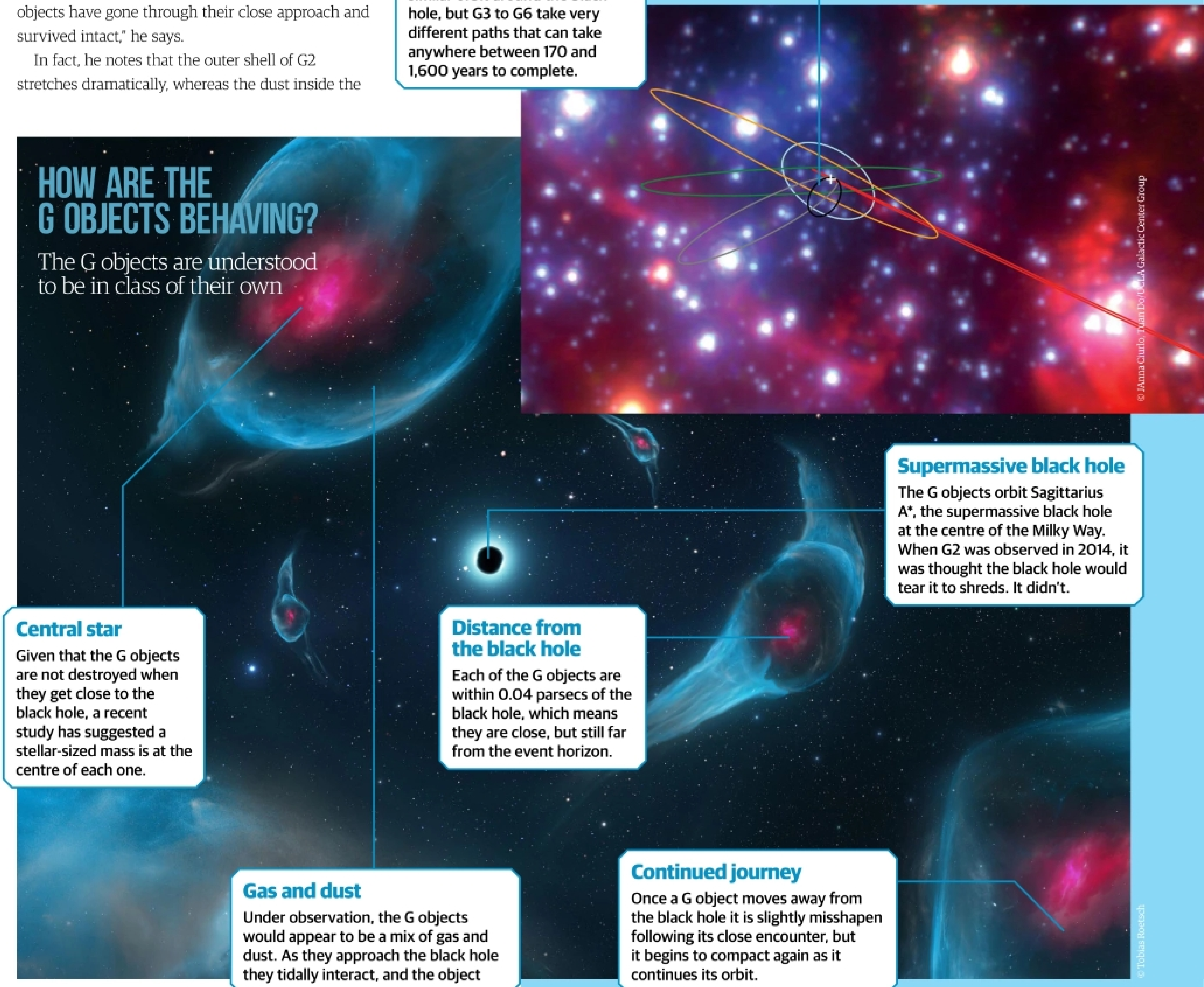
In fact, he notes that the outer shell of G2 stretches dramatically, whereas the dust inside the gas doesn't stretch much when it gets close to Sgr A*. It points to there being stellar objects with a strong gravitational pull inside the G objects, and this would explain why they are compact and able to survive the immense gravitational pull of the black hole. But how did they get to be that way? Well, according to UCLA astronomers the six objects were most likely binary stars that merged due to the supermassive black hole's strong gravitational force. In other words, a system of two stars orbiting each other would have been pulled together into one entity over the course of more than a million years, Ghez says.

"The merged-binary hypothesis fits the theoretical expectations for what should happen to binary stars orbiting fairly closely around a supermassive black hole," explains Morris. "Binary stars are commonplace in the galaxy, so one should expect that to be true in the galactic centre as well, and their abundance is something that we are closely looking into."

He says another hypothesis to consider is one that suggests stars in the galactic centre are so close to each other because of the high stellar density that they occasionally encounter each other at high speeds in glancing collisions. "This could levitate much of the stellar atmosphere, causing it to become distended, cold and dusty, which is what the G objects are," Morris says. "It would take a long time for such bloated stars to settle down."

HOW ARE THE G OBJECTS BEHAVING?

The G objects are understood to be in class of their own



Different orbits

The objects G1 and G2 follow a similar orbit around the black hole, but G3 to G6 take very different paths that can take anywhere between 170 and 1,600 years to complete.

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Supermassive black hole

The G objects orbit Sagittarius A*, the supermassive black hole at the centre of the Milky Way. When G2 was observed in 2014, it was thought the black hole would tear it to shreds. It didn't.

Central star

Given that the G objects are not destroyed when they get close to the black hole, a recent study has suggested a stellar-sized mass is at the centre of each one.

Distance from the black hole

Each of the G objects are within 0.04 parsecs of the black hole, which means they are close, but still far from the event horizon.

Gas and dust

Under observation, the G objects would appear to be a mix of gas and dust. As they approach the black hole they tidally interact, and the object

Continued journey

Once a G object moves away from the black hole it is slightly misshapen following its close encounter, but it begins to compact again as it continues its orbit.

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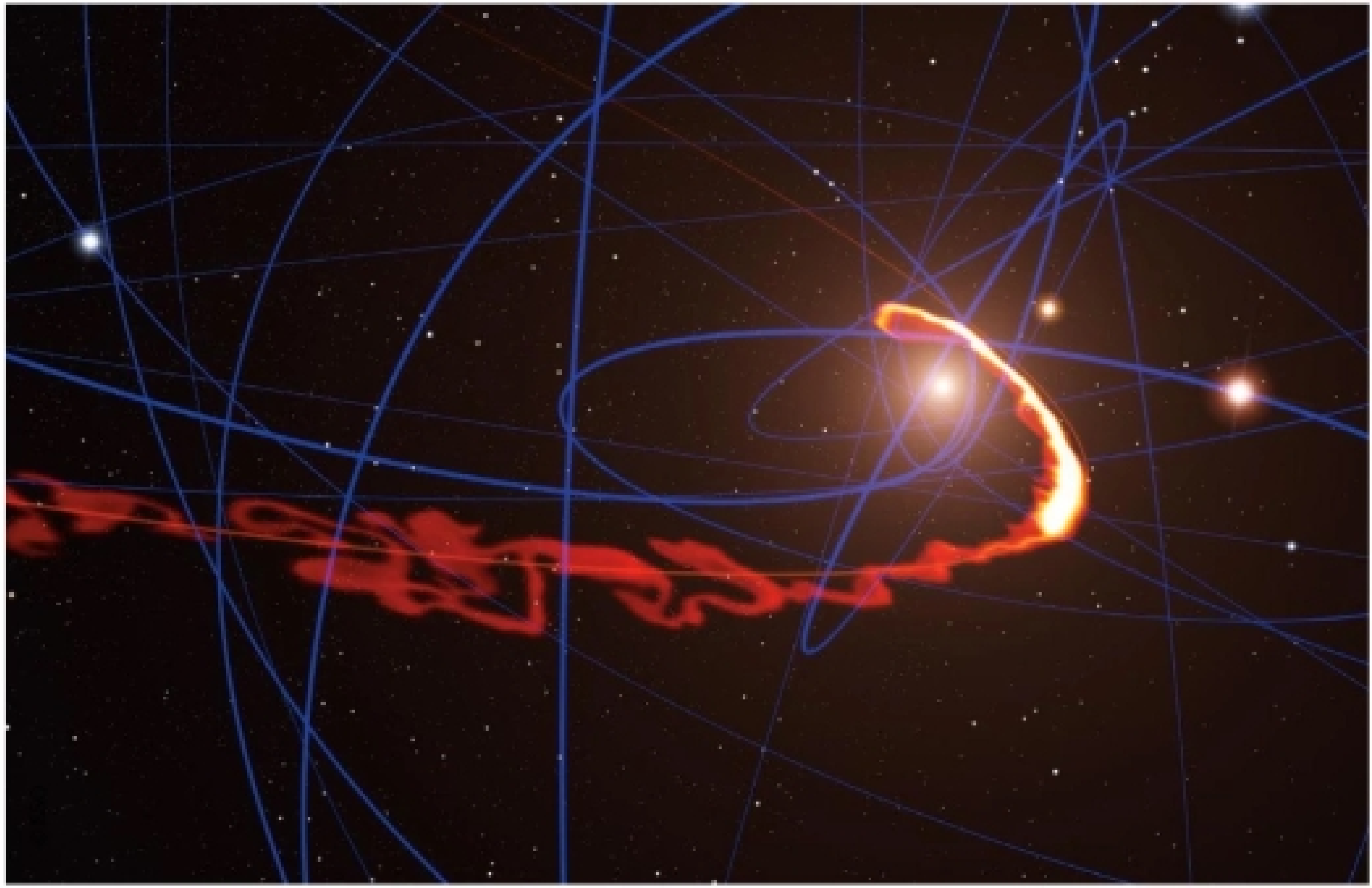

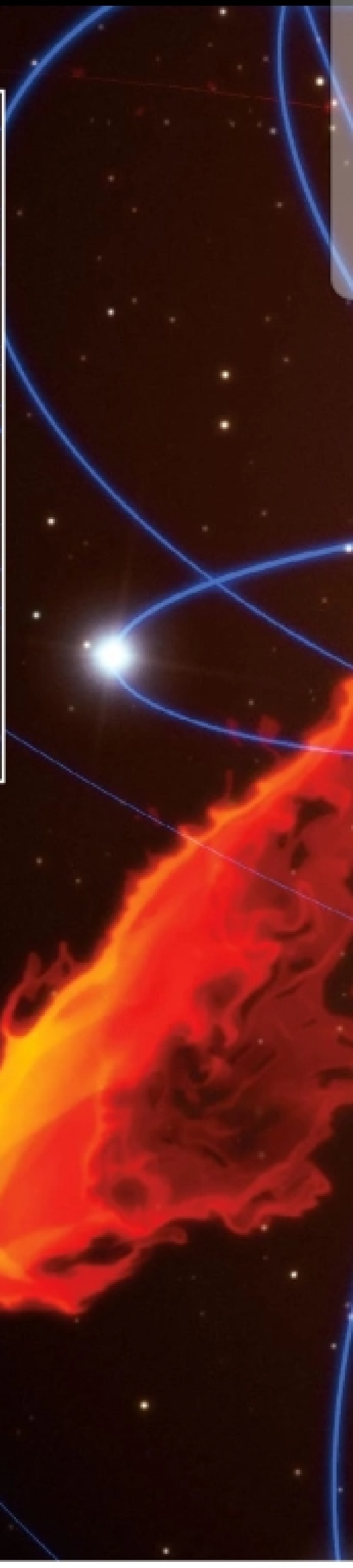

Others have suggested that the objects are a protostar surrounded by an accretion disc. "But that would necessarily be very young, and there are reasons to question whether star formation has taken place sufficiently recently for that hypothesis to be viable," Morris counters.

As for the German team, Morris says: "They are not willing to admit that we can rule out the gas cloud hypothesis. They have argued that such a cloud can stay together during its close passage because of the high external pressure of the gas there. I don't think that prevents the cloud from being tidally disrupted."

The evidence for them being cocooned stars is backed up by the angular momentum of the objects in their orbits around the black hole. "Because they have angular momentum in their orbits around the black hole, they will keep going in the same way that the Earth keeps going in its orbit around the Sun without getting pulled in, especially if they are stars, because that angular momentum cannot be removed," he says.

If the G objects are indeed merged binary stars, then it has wide ramifications for astronomy and scientific understanding. In a statement announcing the discovery of G3 through to G6 and the study into such objects, it was pointed out that the black hole may be driving binary stars to merge.

Ghez said in the statement: "It's possible that many of the stars we've been watching and not understanding may be the end product of mergers that are calm now. We are learning how galaxies and black holes evolve. The way binary stars interact with each other and with the black hole is very different from how single stars interact with other single stars and with the black hole."

Morris claims G objects are likely relevant to the growth of supermassive black holes in galactic nuclei. "There is a long-standing problem of how such black holes get fed and how they can grow to have the masses that they have," he tells us.

"Both stars and interstellar gas contribute to their growth, but in spite of their strong gravity black holes are so small that it is very hard to get matter to reach them and to go all the way down to their event horizon to become part of the black hole.

Above: When G2 was observed to be getting close to Sgr A*, astronomers believed it would be ripped apart

Right: When using Chandra to observe Sgr A*'s reaction to G2 in 2014, a large X-ray flare was detected from the supermassive black hole

IN THE CHAIR WITH G2'S DISCOVERER

Astronomer Stefan Gillessen of the Max Planck Institute for Extraterrestrial Physics in Germany discovered the object G2 in 2011. He believes it is most likely a compact gas cloud

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When G2 was seen heading towards Sgr A* in 2014, how surprised were you to see it emerge relatively unscathed?

I wasn't really that surprised – the simulations we carried out were not suggesting there would be a collision: they showed that the gas could run around Sgr A*.

What prevented the object from being torn apart in its entirety?

There's a balance between centrifugal forces and gravitational forces as an object approaches a black hole, but it's extremely difficult to fall in. For a circular object there's a very nice balance, but for an eccentric orbit there is swinging back and forth. Since the orbit of G2 is highly eccentric, you simply expect that it comes close to a black hole only for tidal forces to step in. The fact the object was tidally torn apart means it was not bound to anything else.

Would that dispel the theory there's a stellar mass inside?

It's hard to prove. The problem is that you can make something hot enough or small enough for it not to be seen in theory, but it is very hard to test. I took the position that there could be a lump of gas because there is gas everywhere in the galaxy.

Are there strong arguments against a hidden stellar mass?

It has been shown that G2 slowed down, and this points to the gas not being gravitationally bound. You would expect the stellar source to continue on the original orbit at the same time as the gas is decelerating. But we haven't seen anything moving out. There is also a theory that this is a merged object – former binary stars colliding and shielding themselves in a cocoon – but six G objects would be too many merged objects out of the 40 stars we see in the galactic centre. Mergers are really rare and they'd need to live for millions of years.

© ESO

"Part of the problem is angular momentum. Orbiting gas and orbiting stars can't usually get too close because of their inherent angular momentum, which presents what is called a centrifugal barrier and makes it hard to feed the black hole. But gas can apparently be pulled off the G objects as they orbit close to the black hole, and that gas can ultimately be drawn into the black hole as it joins the accretion flow of matter onto the black hole."

If correct, it would mean that G objects are contributing to the growth of black holes. They're probably not the dominant contributor, but it might help to explain why, in September last year, the UCLA team was also able to observe the brightest light in 24 years of supermassive black hole observation, pointing to the galaxy having a scrumptiously large feast of interstellar gas and dust. The team is now looking for more G objects, and it says it has identified some candidates. "We will continue to identify more G objects and to determine their orbits more precisely with more measurements in coming years," Morris says.

"The next generation of big telescopes will be very useful for seeing in much improved detail what happens as G objects swing closely around the black hole in their orbits, and they will help to tell us how much mass they lose in each passage." Key quests will involve trying to find binary systems which haven't yet merged but which may later do so and become G objects. They will also look at whether the black hole becomes more active after a G object passes nearby.

"The answer to that is something we are pursuing now," Morris says. "We recently reported an infrared observation last year that the black hole underwent an enormous flare. Can we associate that with a G object passage a few years earlier? Or is that just some random lump of matter falling into the black hole?"

One thing's for sure, the issue of G objects is not about to be forgotten, and they represent another mysterious puzzle to solve.

> **"THE STARS WE'VE BEEN WATCHING AND NOT UNDERSTANDING MAY BE THE END PRODUCT OF MERGERS THAT ARE CALM NOW"** **ANDREA GHEZ**

THE THEORIES

Is a star really at the centre of the mysterious clouds of gas and dust?

Binary stars have merged

As one of two most likely scenarios, this theory suggests the G objects are merged binary stars that have an outer layer of gas and dust. It suggests that close proximity to black holes causes great disturbance and increases the chance of collision. As material is expelled during such events, the stellar mass becomes hidden.

Compact gas clouds

The other major theory suggests the G objects are dusty ionised gas clouds that follow highly eccentric orbits around the black hole. The suggestion is that it is ultra-rare for stars to exist inside gas clouds that are so thick they prevent light from shining through. G2 was also seen to slow down following its black hole encounter – something less likely for dense stars.

The origin is star S2

If the G objects are simply pure gas clouds, then a theory points to the star S2 shedding material as it orbits the black hole. G1 and G2 follow similar orbits, so could be part of the same stream of gas, but that doesn't explain the wildly different orbits that are taken by G3 through to G6. Perhaps they are not all of the same category.

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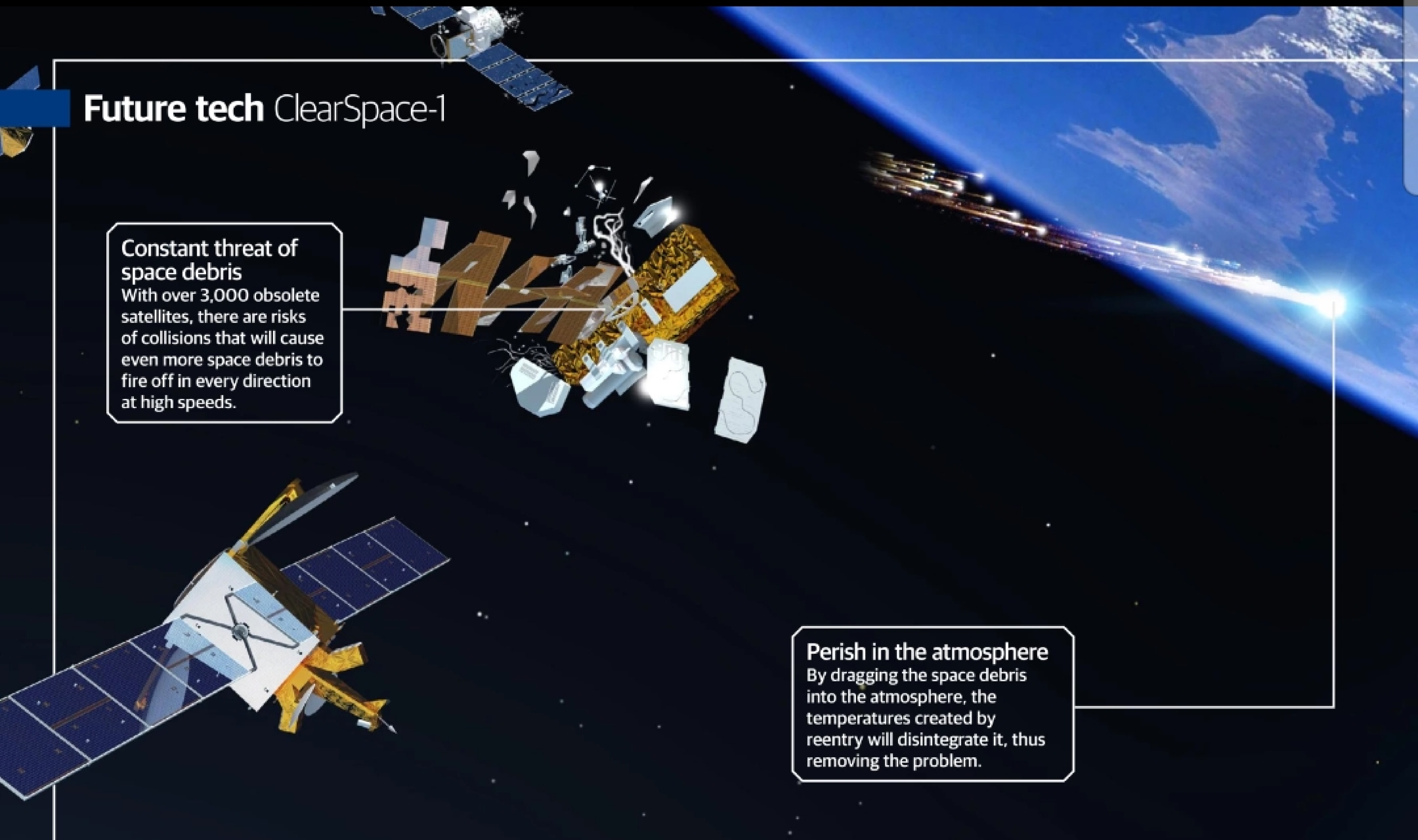


Constant threat of space debris
With over 3,000 obsolete satellites, there are risks of collisions that will cause even more space debris to fire off in every direction at high speeds.

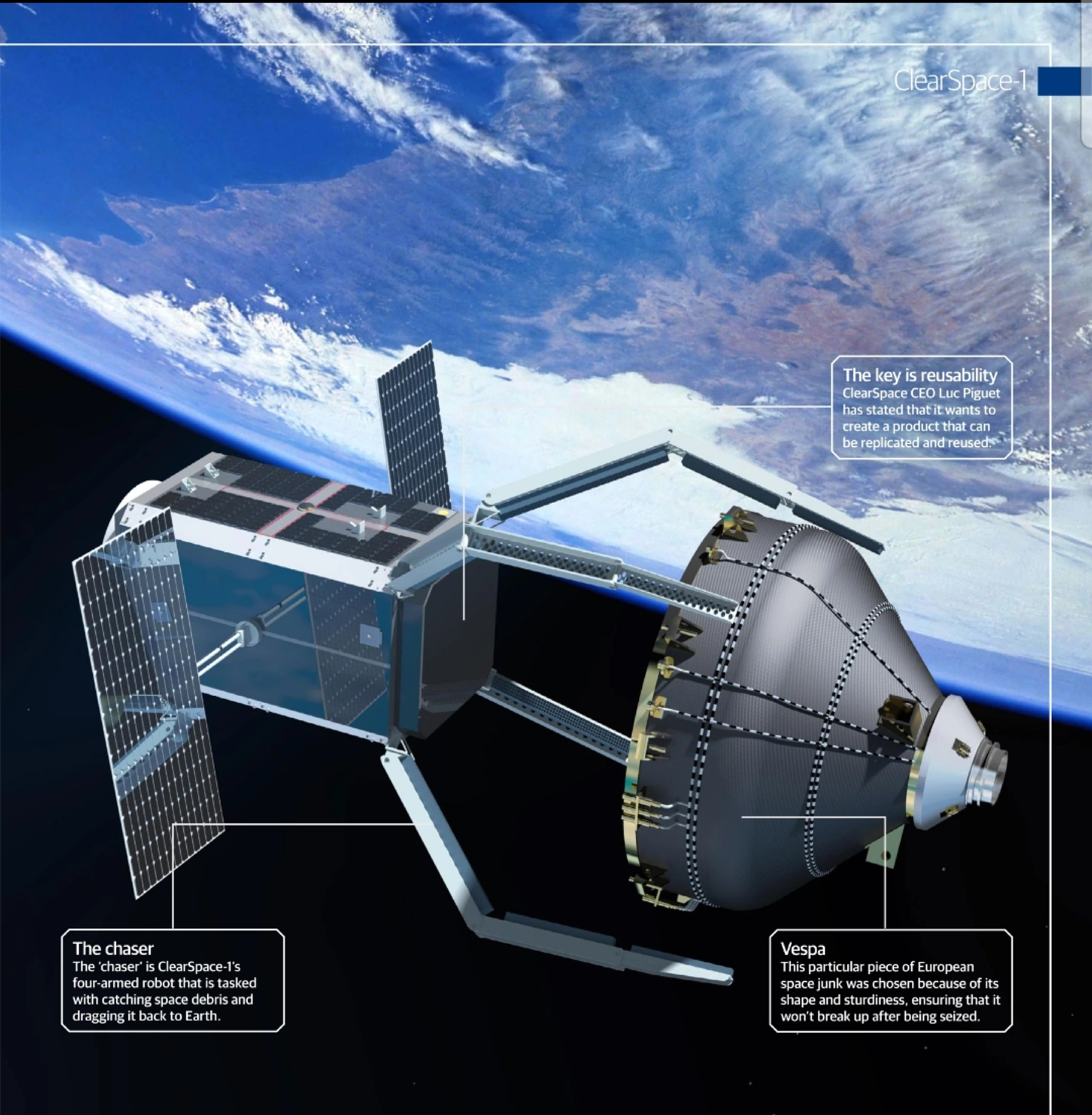
Perish in the atmosphere
By dragging the space debris into the atmosphere, the temperatures created by reentry will disintegrate it, thus removing the problem.

CLEARSPACE-1 THE KAMIKAZE SPACE CLEANER

This European mission will be purging low-Earth orbit with a space-debris removal plan for 2025

The European Space Agency (ESA) has recently commissioned its first mission to begin the clean up of space debris. Space debris has become an increasing problem with the ever-growing population of satellites in low-Earth orbit, and there are currently limited efforts to clean the mechanical mess that is left behind in space. This new European mission will launch an experimental, four-armed robot named ClearSpace-1 in 2025 to see if this could be the answer for a large-scale cosmic clean-up. If successful, this robot could soon be hugging pieces of space junk and performing a kamikaze dive into Earth's atmosphere, where they will both burn up upon reentry.

Material drifts around in low-Earth orbit, left over from rockets, space stations and satellites. In fact, there are nearly 2,000 live satellites currently parked in low-Earth orbit, and over 3,000 defunct ones. This is the space equivalent of having 3,000 cars break down and then just leaving them on the road. It would likely cause an accident. The International Space Station in particular is constantly at risk. Its windows could be pierced with a piece of space junk travelling



The key is reusability
ClearSpace CEO Luc Piguet has stated that it wants to create a product that can be replicated and reused.

The chaser
The 'chaser' is ClearSpace-1's four-armed robot that is tasked with catching space debris and dragging it back to Earth.

Vespa
This particular piece of European space junk was chosen because of its shape and sturdiness, ensuring that it won't break up after being seized.

at an average speed of around 36,000 kilometres (22,370 miles) per hour. This puts the lives of astronauts at risk.

"The space debris issue is more pressing than ever before," says Luc Piguet, founder and CEO of ClearSpace, the Swiss junk-removal start-up partnering with the ESA. "Today we have nearly 2,000 live satellites in space and more than 3,000 failed ones. And in the coming years the number of satellites will increase by an order of magnitude, with multiple mega-constellations made up of hundreds or even thousands of satellites planned for low-Earth orbit."

This mission, scheduled to launch in 2025, will involve launching the ClearSpace-1 'chaser' satellite into low-Earth orbit, where it will rendezvous with a piece of space debris named Vespa. The defunct junk's full name is the 'Vega Secondary Payload Adapter', and it is the 100-kilogram (220-pound) upper stage of a Vega rocket, left over from a spaceflight in 2013 and still orbiting about 800 kilometres (500 miles) above Earth's surface.

After the chaser latches onto Vespa, which is a similar size to a small satellite, it will undergo a controlled reentry into the atmosphere of Earth and will finish in a blaze of glory under the supervision of the ESA.

As there is so much debris to clean up, this mission alone will surely not be enough. Even if all satellite launches were to stop tomorrow, the amount of space debris would still increase due to collisions and the resulting cascade effect. ClearSpace-1 is certainly a step in the right direction, however, as it will remove a larger piece of debris while simultaneously providing vital information about the technologies and techniques involved – and needed – for such an operation.

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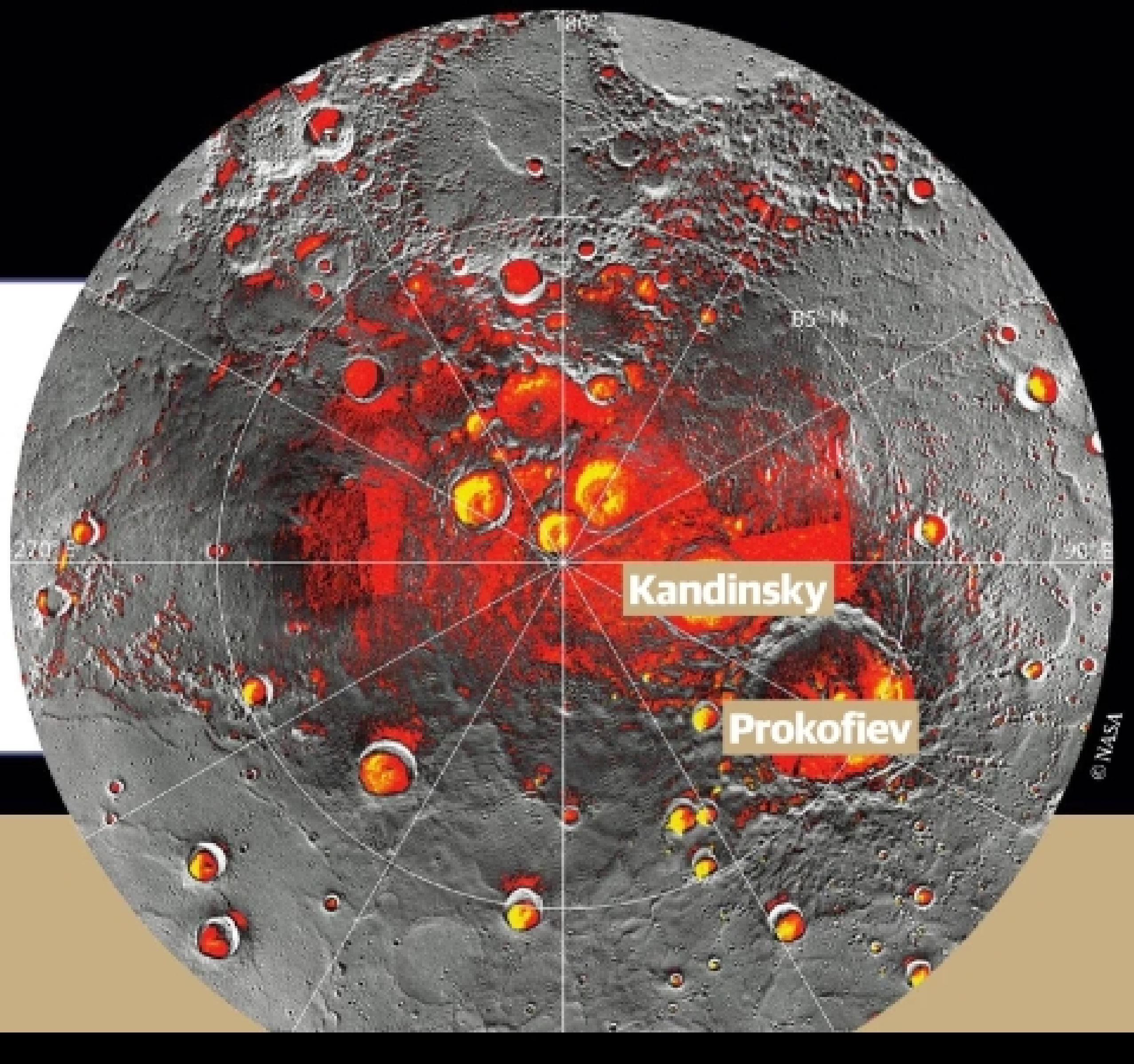
WHAT'S NEW AT MERC

Scientists are still busy analysing data from the MESSENGER mission – and it has plenty of surprises

Reported by Andrew May

ICE ON A HOT PLANET

▶ A view of the area around Mercury's north pole, with regions that permanently lie in shadow shown in red and suspected traces of ice shown in yellow.



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URY?

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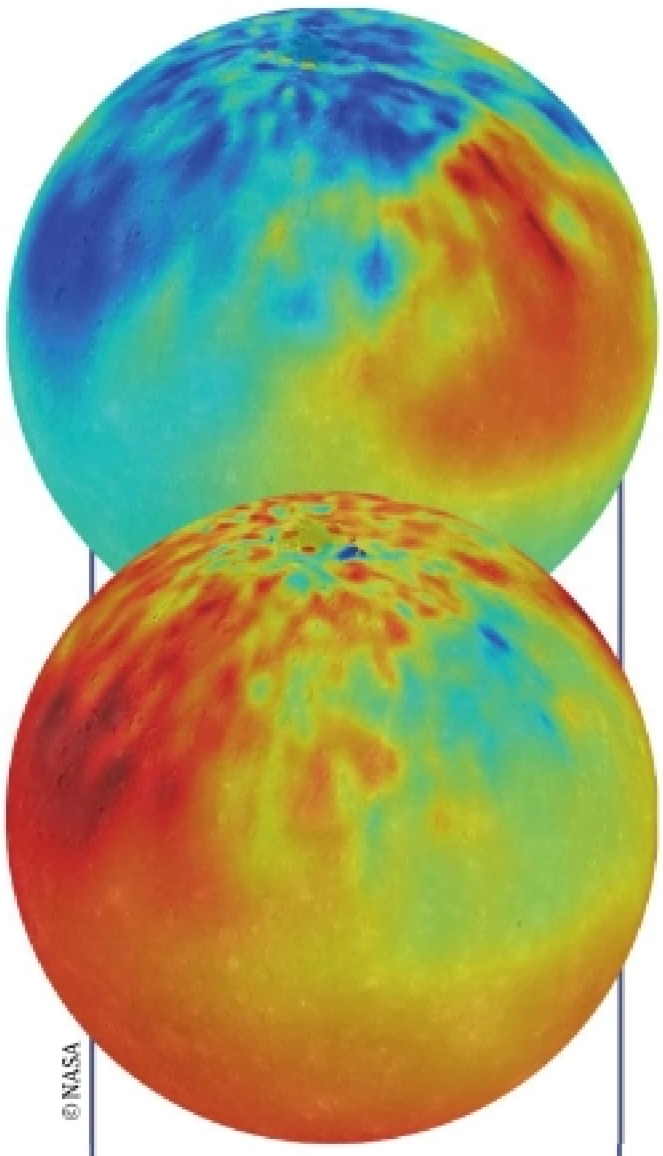

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ELEMENTS THAT 'SHOULDN'T BE THERE'

▲ MESSENGER's instruments included spectrometers to analyse the chemical composition of Mercury's surface – they discovered a surprisingly high level of volatile elements such as sulphur and potassium.

Which planet is Earth's nearest neighbour in the Solar System? The obvious answer is Venus, which makes the closest approach to us - but it spends half its orbit on the other side of the Sun, when it's further away from us than Mercury. It was only last year that Tom Stockman, a graduate research assistant at Los Alamos National Laboratory, New Mexico, and colleagues crunched the numbers to work out which planet is actually closest on average - and they were as surprised as anyone by the answer: "When averaged over time, Earth's nearest neighbour is in fact Mercury," they wrote.

Despite its proximity, Mercury has always been a mysterious planet due to the difficulty of observing it through Earth-based telescopes. That's down to a combination of its small size and the fact that it never gets very far from the Sun in the sky. The only time it makes a really spectacular sight, in fact, is when it passes directly in front of the Sun during a transit of Mercury - like the one that took place a few months ago in November 2019.

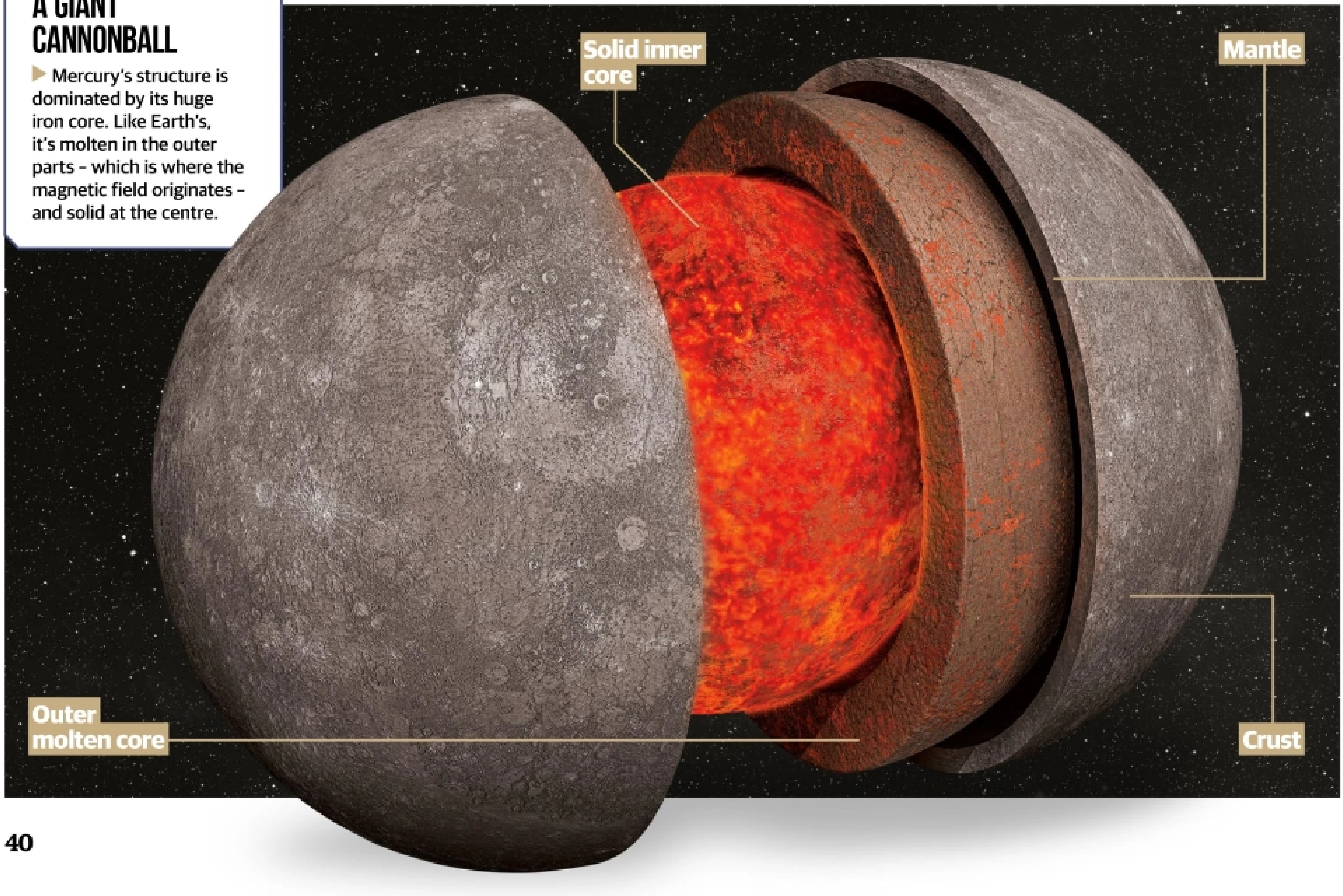
If Mercury is a difficult planet to observe from Earth, it's not an easy destination for spacecraft either. That's partly because a spacecraft speeds up under the effect of gravity as it falls towards the Sun - and then its rocket engine has to work hard to lose that excess speed when it gets to Mercury. Another problem is the extreme heat - well over 400 degrees Celsius (752 degrees Fahrenheit) - in the vicinity of Mercury, which poses serious challenges for spacecraft designers. Since the dawn of the space age, only two space probes have been to Mercury - Mariner 10 in the 1970s, followed by MESSENGER more recently, both by NASA.

The photographs sent back by Mariner 10, which made three close passes of Mercury in 1974 and 1975, revealed a desolate, crater-studded landscape that looks a lot like our Moon. But the mission had a surprise for scientists in its discovery of a well-defined magnetic field around the planet. It's a hundred times weaker than Earth's field, but Venus and Mars don't have internal magnetic fields at all, and Mercury wasn't expected to either.

A closer look at Mercury's magnetic field was one of the key objectives of NASA's follow-up mission, MESSENGER, which entered orbit around the planet in March 2011. It remained there until it ran out of manoeuvring propellant four years later - and in the final few months the mission controllers got increasingly bold. They dipped the spacecraft to just 15 kilometres (9.3 miles) above the planet, allowing them to measure relic magnetism in the surface rocks. "The signals we detected are really small, and very hard to measure," explains planetary geophysicist Catherine Johnson. "We'd never have been able to measure them if not for these really

A GIANT CANNONBALL

▶ Mercury's structure is dominated by its huge iron core. Like Earth's, it's molten in the outer parts – which is where the magnetic field originates – and solid at the centre.



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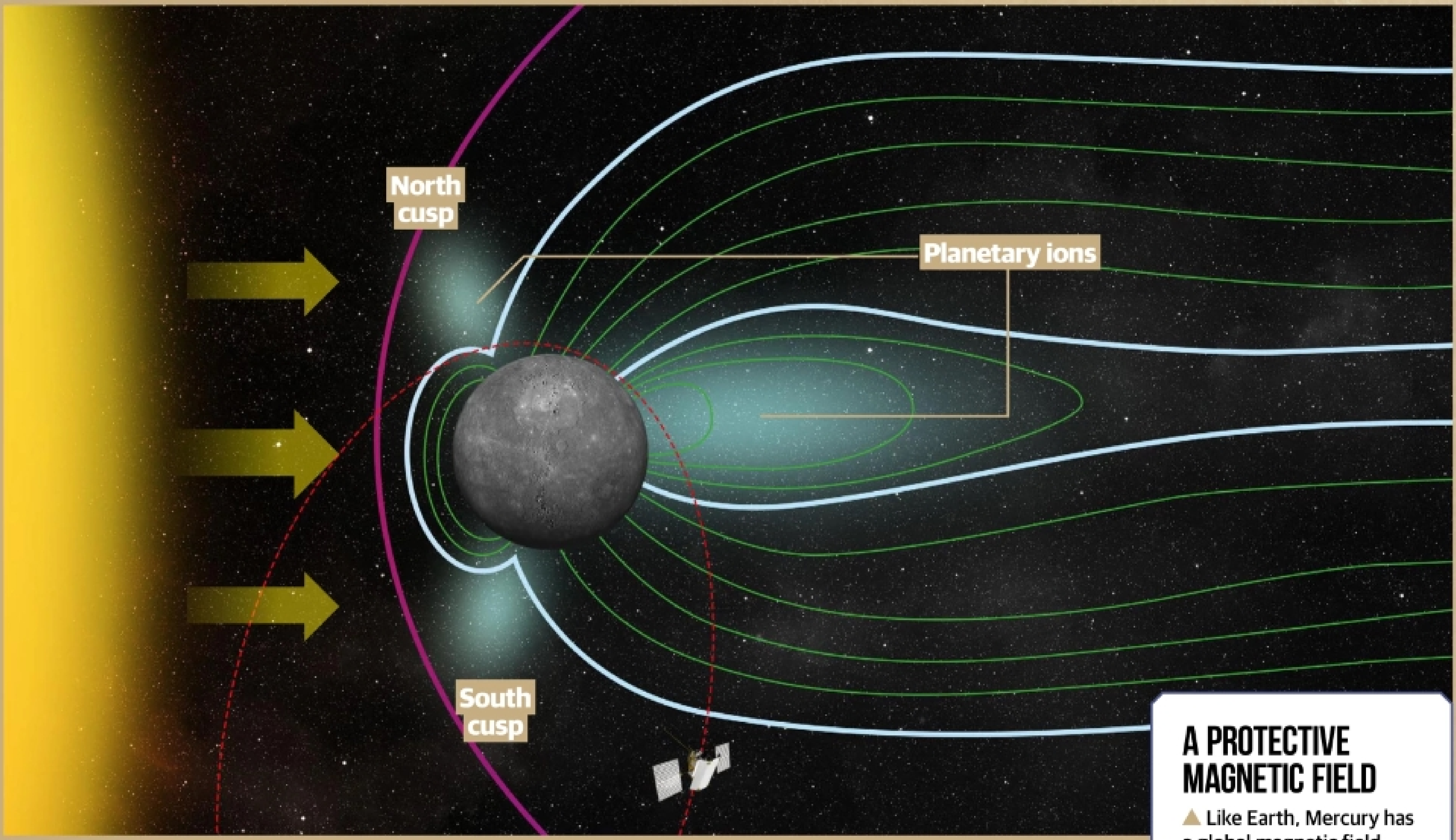
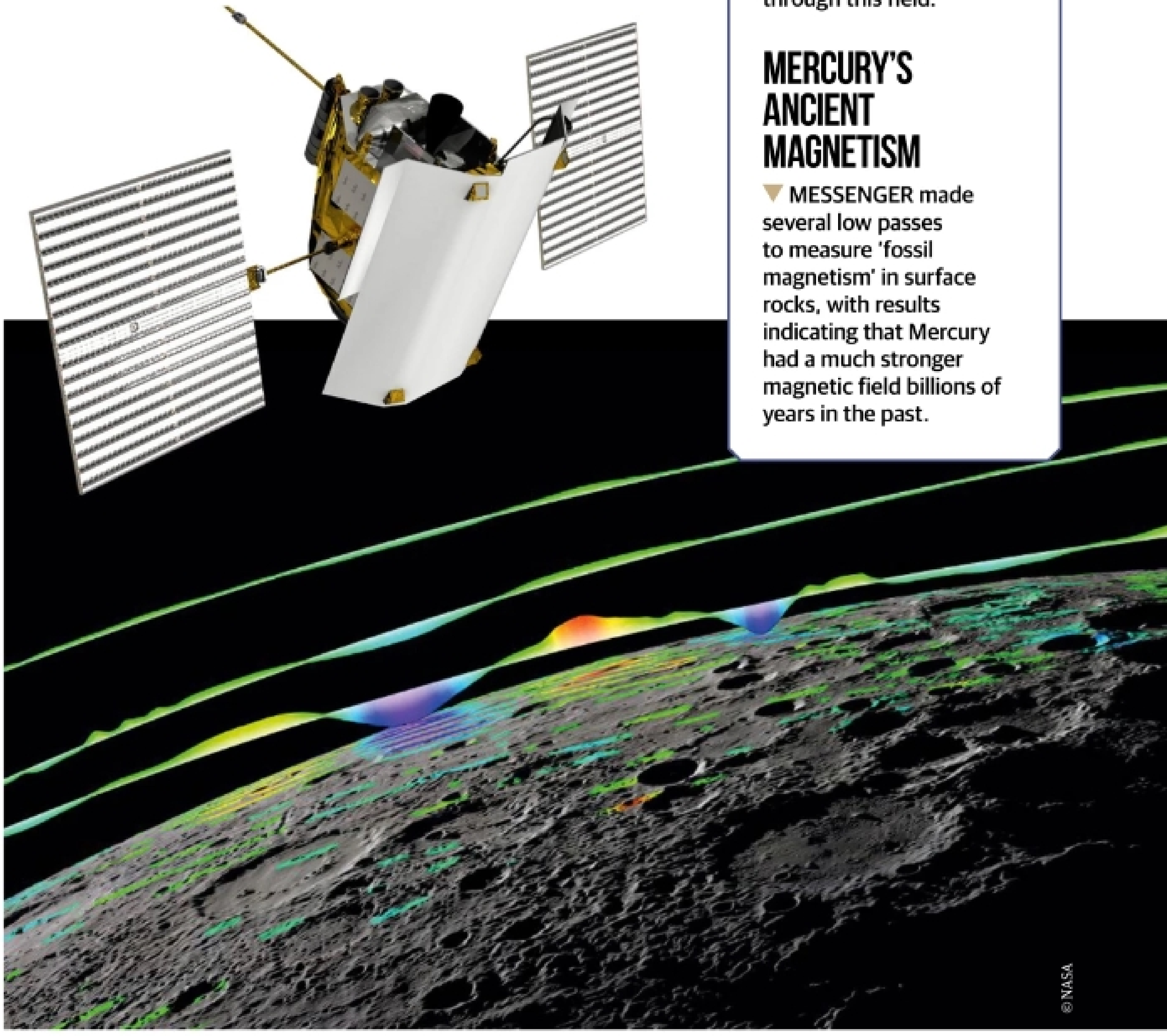


A PROTECTIVE MAGNETIC FIELD

▲ Like Earth, Mercury has a global magnetic field which helps to shield it from the solar wind. The dashed red line shows MESSENGER's orbit through this field.

MERCURY'S ANCIENT MAGNETISM

▼ MESSENGER made several low passes to measure 'fossil magnetism' in surface rocks, with results indicating that Mercury had a much stronger magnetic field billions of years in the past.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> **"WE'D NEVER HAVE BEEN ABLE TO MEASURE THEM IF NOT FOR THESE REALLY RISKY LOW-ALTITUDE OBSERVATIONS"** CATHERINE JOHNSON

risky low-altitude observations in the last few months of the MESSENGER mission."

The measurements indicated that not only is Mercury's magnetism very old – going back at least 3.8 billion years – but it was much stronger in the past, "comparable to the strength of Earth's magnetic field today," according to Johnson.

When all its propellant was used up, MESSENGER was deliberately crashed into Mercury's surface – the first Earth-made artefact on the planet – on 30 April 2015. From NASA's point of view the mission was a huge success, repeatedly surprising researchers with its discoveries. "In the end, most of what we considered to be gospel about Mercury turned out to be a little different than we thought," as mission scientist William McClintock said at the time.

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ON COURSE FOR MERCURY

▶ The two spacecraft making up the exciting BepiColombo mission, from the European and Japanese space agencies, were launched in October 2018 and should go into orbit around Mercury in late 2025.

RETHINKING MERCURY'S ORIGIN

▼ It used to be thought that Mercury suffered a huge impact which stripped off its outer layers, but that's less likely now we know there are volatiles on the surface.

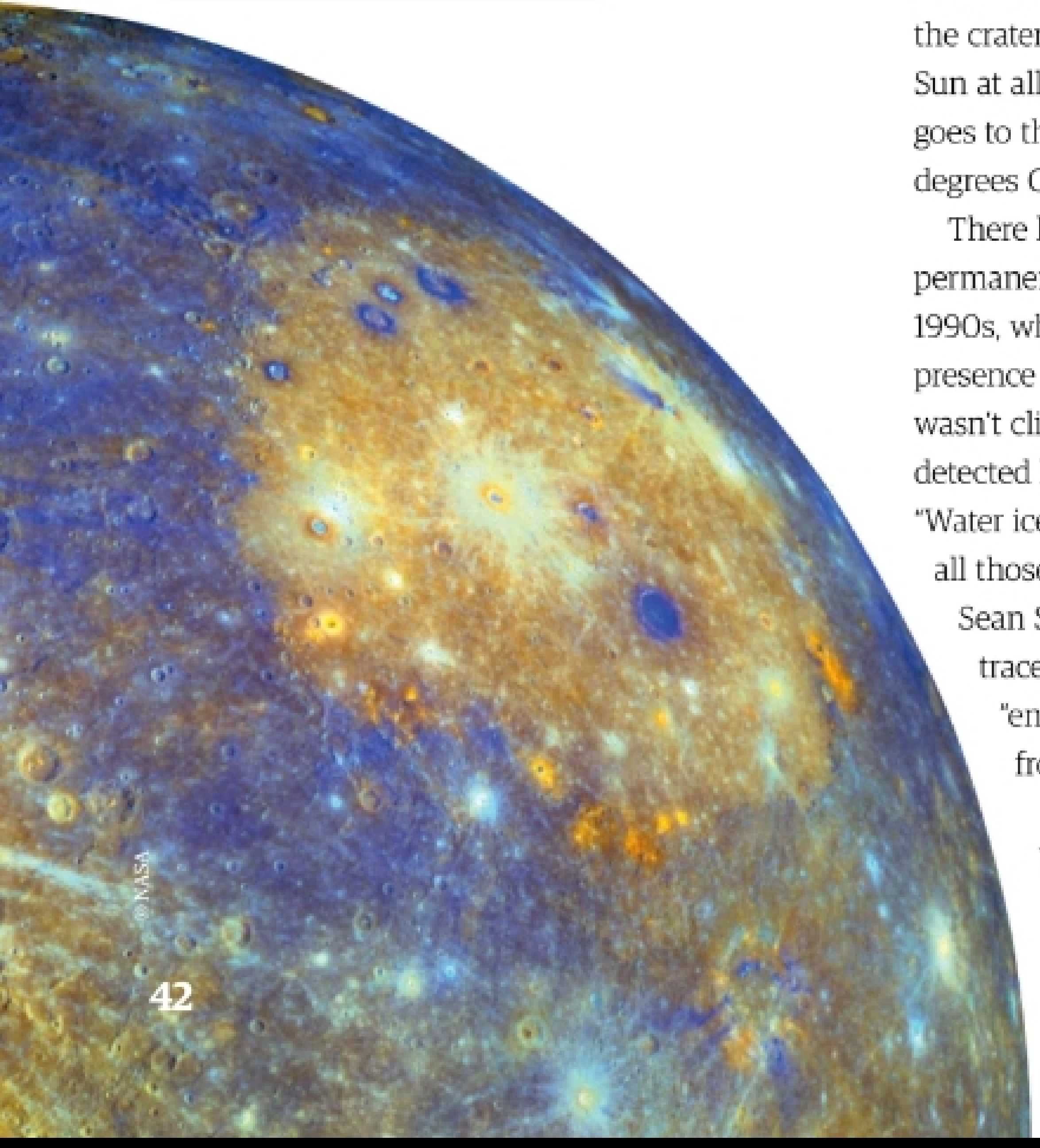
"MOST OF WHAT WE CONSIDERED TO BE GOSPEL ABOUT MERCURY TURNED OUT TO BE A LITTLE DIFFERENT THAN WE THOUGHT" WILLIAM MCCLINTOCK

Among MESSENGER's biggest surprises was the discovery of water ice on Mercury. This seems odd, given the extremely high surface temperatures in direct sunlight. But there are spots inside some of the craters near the planet's poles that never see the Sun at all, and consequently the temperature there goes to the opposite extreme – closer to minus 200 degrees Celsius (minus 328 degrees Fahrenheit).

There had been hints of ice inside these permanently shadowed craters as long ago as the 1990s, when radar measurements indicated the presence of highly reflective material. The issue wasn't clinched, however, until MESSENGER detected hydrogen atoms in the same locations. "Water ice is the only candidate we've got that fits all those observations," as principal investigator Sean Solomon explained. It's not just a few traces of ice, either – according to Solomon it's "enough ice to encase Washington DC in a frozen block two-and-a-half miles deep".

Another unexpected finding was a brand-new type of surface feature that isn't seen anywhere else in the Solar System except Mercury. Called 'hollows', these are shallow depressions found inside many of the planet's craters. They're believed to have formed when volatile components in the surface material evaporated, causing the remaining material to collapse. "The hollows are one of the most viscerally interesting discoveries from the mission," according to another MESSENGER scientist, Steve Hauck. "They were completely unexpected – a new landform, and one that appears to form by loss of rock to space."

The idea that volatile materials boiled off Mercury in the distant past seems reasonable enough, given its hot location close to the Sun. What would be more surprising would be to find volatile materials still on the planet's surface today – and yet that's exactly what MESSENGER did find. It's a subject Brian Cox talked about in his TV series *The Planets* last year. "The discovery of relatively large concentrations of elements like sulphur and potassium on Mercury's surface was a huge surprise," he said. "So Mercury is an enigma, and discoveries like these force us to completely



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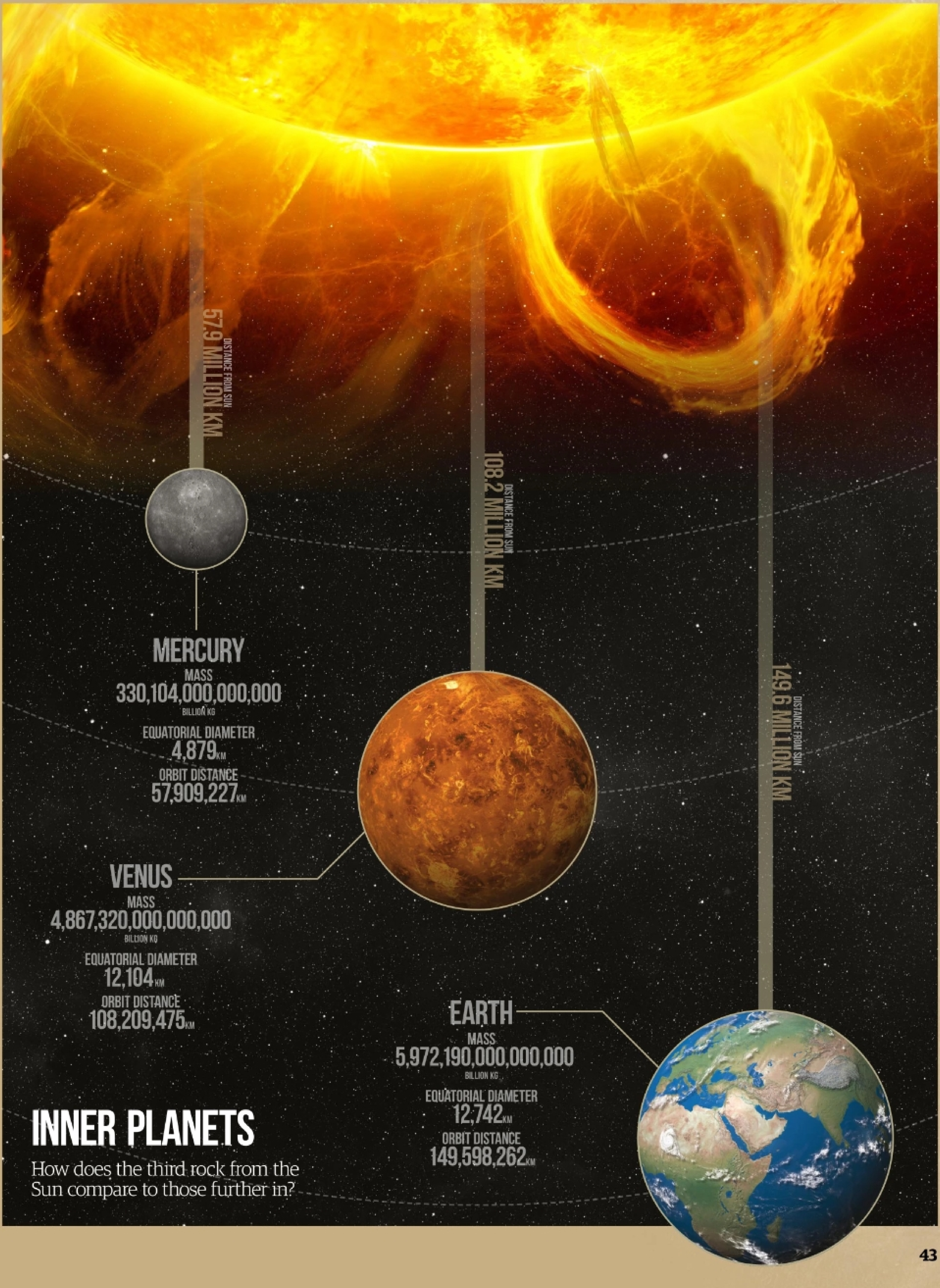
INNER PLANETS

How does the third rock from the Sun compare to those further in?



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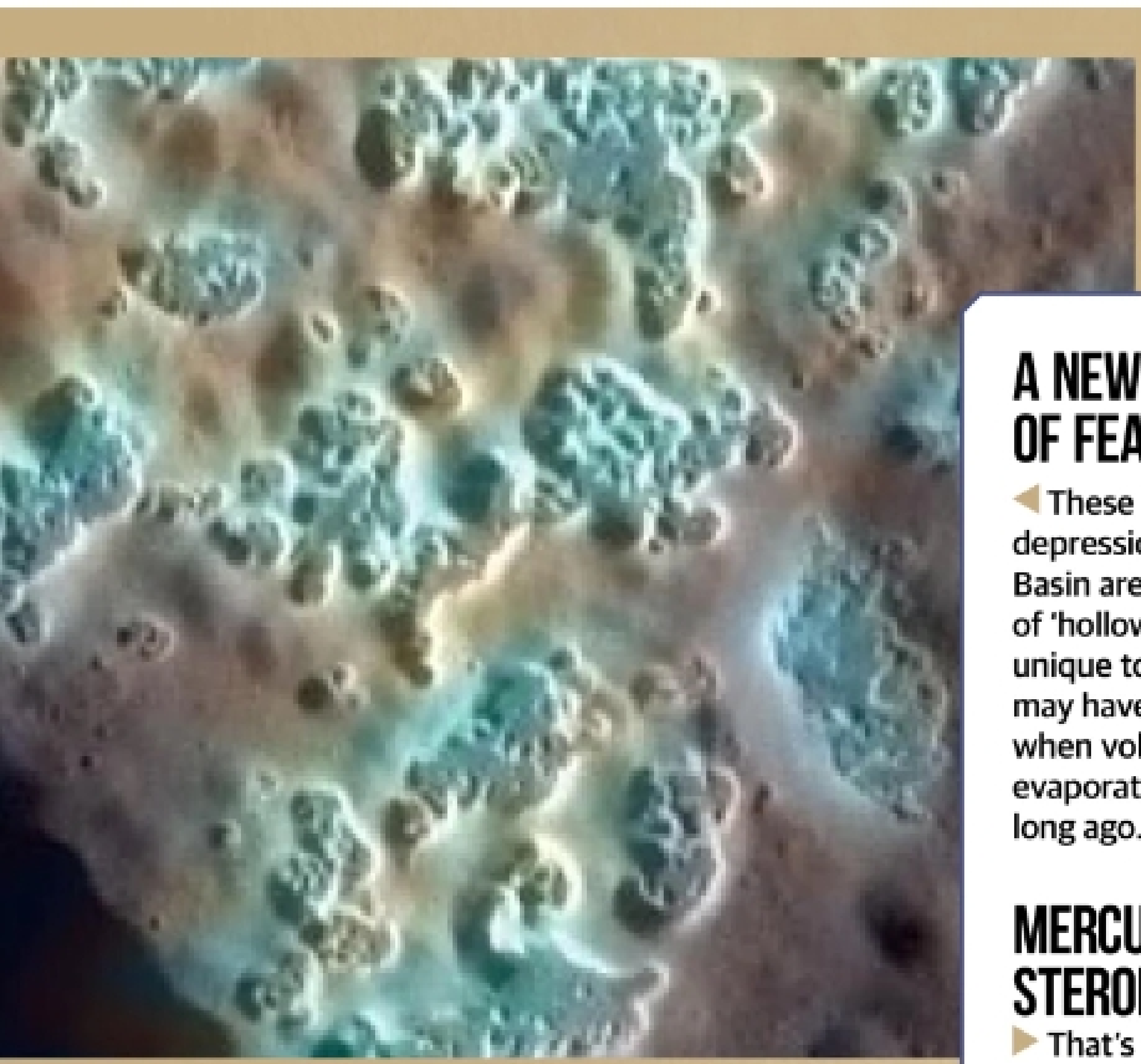
rethink our theories about the formation of the planet."

The problem with this new discovery was that it didn't fit in with existing ideas about Mercury's origin, which had been developed over the years to explain its unusual internal structure. Like Earth, the planet is made up of a rocky crust and mantle surrounding an iron-rich core - but in Mercury's case the core is huge, making up almost 85 per cent of its volume. For a long time it was assumed that Mercury must have started out looking very similar to Earth in size and composition. Then, billions of years ago, it had its outer layers knocked off in a collision with a huge asteroid.

The problem with that theory is it doesn't explain why there's so much sulphur and potassium on Mercury's surface today. It now seems likely that Mercury formed much as it is now, and that its large core was a consequence of the different physical conditions in the inner parts of the early Solar System compared with further out where the other planets formed. That's supported by the discovery of exoplanets orbiting close to other Sun-like stars, which also appear to have large metallic cores like Mercury.

Despite its numerous discoveries, MESSENGER left plenty of unanswered questions - but fortunately there's another mission, BepiColombo, on its way to Mercury right now. Made up of two separate spacecraft, the ESA's Mercury Planetary Orbiter and the Japan Aerospace Exploration Agency's Mercury Magnetospheric Orbiter, it's due to arrive in 2025. With 16 scientific instruments, researchers are hoping BepiColombo will make just as many discoveries as MESSENGER did.

> **"THE DISCOVERY OF RELATIVELY LARGE CONCENTRATIONS OF ELEMENTS LIKE SULPHUR AND POTASSIUM ON MERCURY'S SURFACE WAS A HUGE SURPRISE"** BRIAN COX

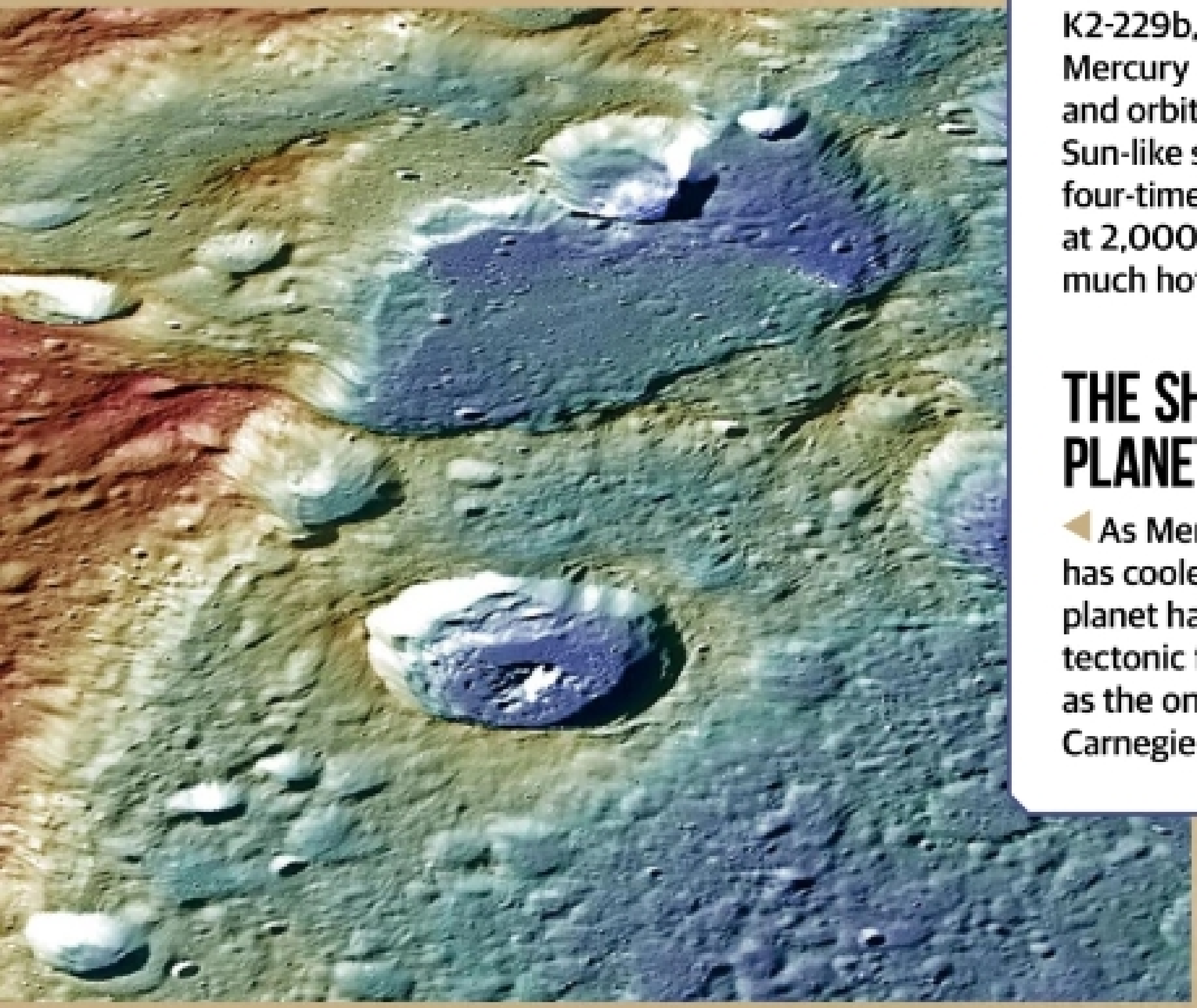


A NEW TYPE OF FEATURE

◀ These rounded depressions in Raditladi Basin are examples of 'hollows' – features unique to Mercury which may have been formed when volatile materials evaporated into space long ago.

MERCURY ON STEROIDS?

▶ That's how NASA described exoplanet K2-229b, which resembles Mercury in being iron-rich and orbiting close to a Sun-like star, but it's four-times bigger and, at 2,000°C (3,632°F), much hotter.



THE SHRINKING PLANET

◀ As Mercury's interior has cooled down, the planet has shrunk, creating tectonic fault lines such as the one pictured here, Carnegie Rupes.

x3 Images © NASA

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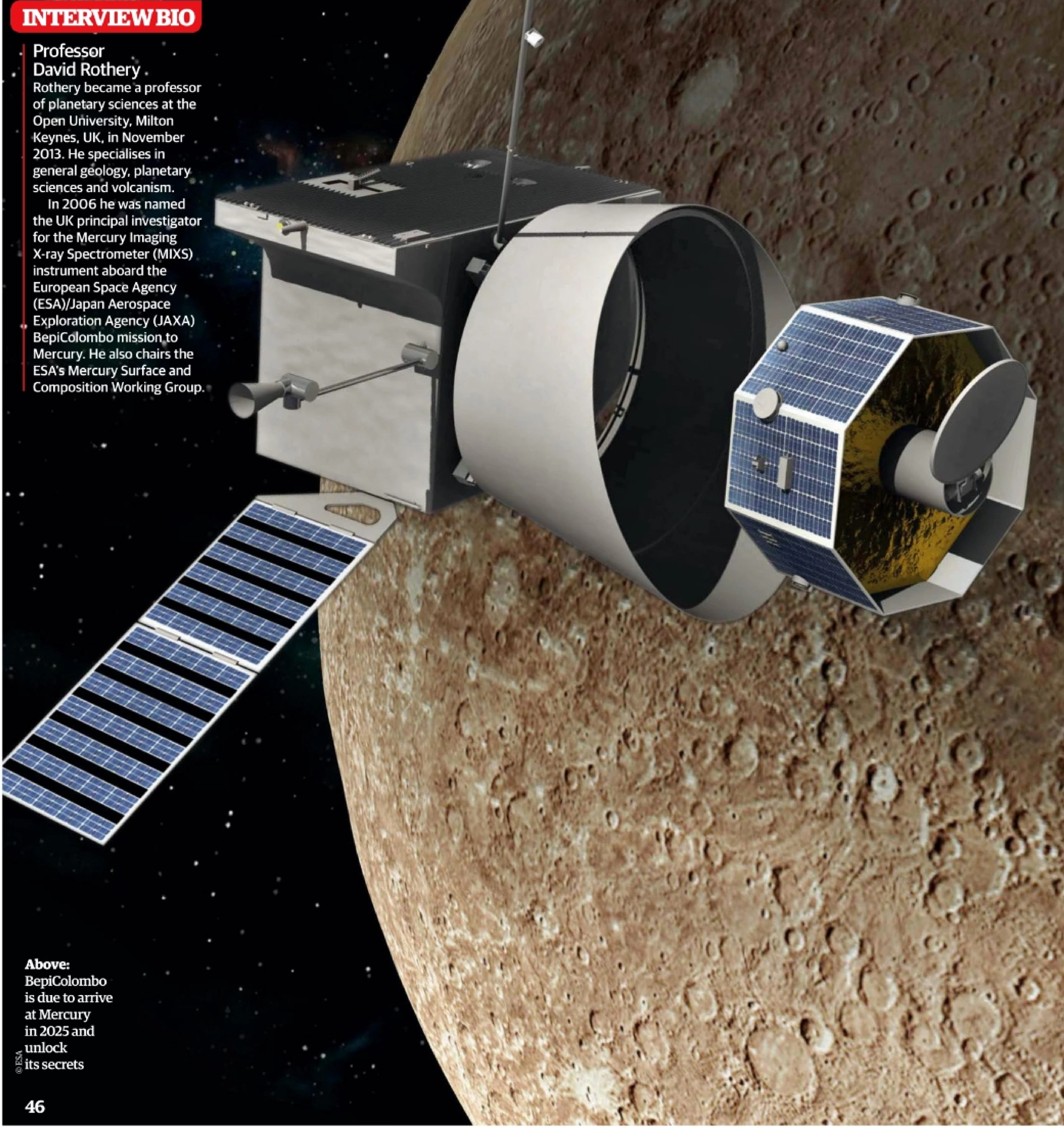
INTERVIEW BIO

Professor David Rothery

Rothery became a professor of planetary sciences at the Open University, Milton Keynes, UK, in November 2013. He specialises in general geology, planetary sciences and volcanism.

In 2006 he was named the UK principal investigator for the Mercury Imaging X-ray Spectrometer (MIXS) instrument aboard the European Space Agency (ESA)/Japan Aerospace Exploration Agency (JAXA) BepiColombo mission to Mercury. He also chairs the ESA's Mercury Surface and Composition Working Group.



Above: BepiColombo is due to arrive at Mercury in 2025 and unlock its secrets

© ESA

MERCURY MISSION: "I'M GLAD WE'RE GOING BACK!"

BepiColombo is shooting for Mercury. Professor David Rothery, a key member of the science team, reveals what's in the pipleline and what we've got to look forward to ahead of its rendezvous with the swift planet in 2025

Reported by Lee Cavendish

What will you be doing in preparation ahead of BepiColombo's arrival at Mercury in 2025?

My role on the MIXS team is to help prepare to make the best observations that we can. MIXS' role towards understanding Mercury's surface and composition is to map all the chemical elements it can, and there are some targets which MIXS will try to stare at, making sure it's collecting observations when it's over these critical targets where we think the composition is unusual. MIXS will map the whole planet, but some small areas need special attention – places where there have been volcanic explosions, or regions called 'hollows', which is where the surface is dissipating away to space. At the present day we think the surface is rotting away. We have very limited compositional measurements of these features from the previous mission, MESSENGER. [BepiColombo] will get much better spatial resolution with the X-ray spectrometer then we've achieved before. We're going to make sure we know in advance where these are and build them into the data-collection schedule for arrival to be sure that it's collecting data when it's over the right targets. I'm making sure that MIXS will collect data over the most important regions. I'm also concerned with making sure that we understand the context of the observations we make.

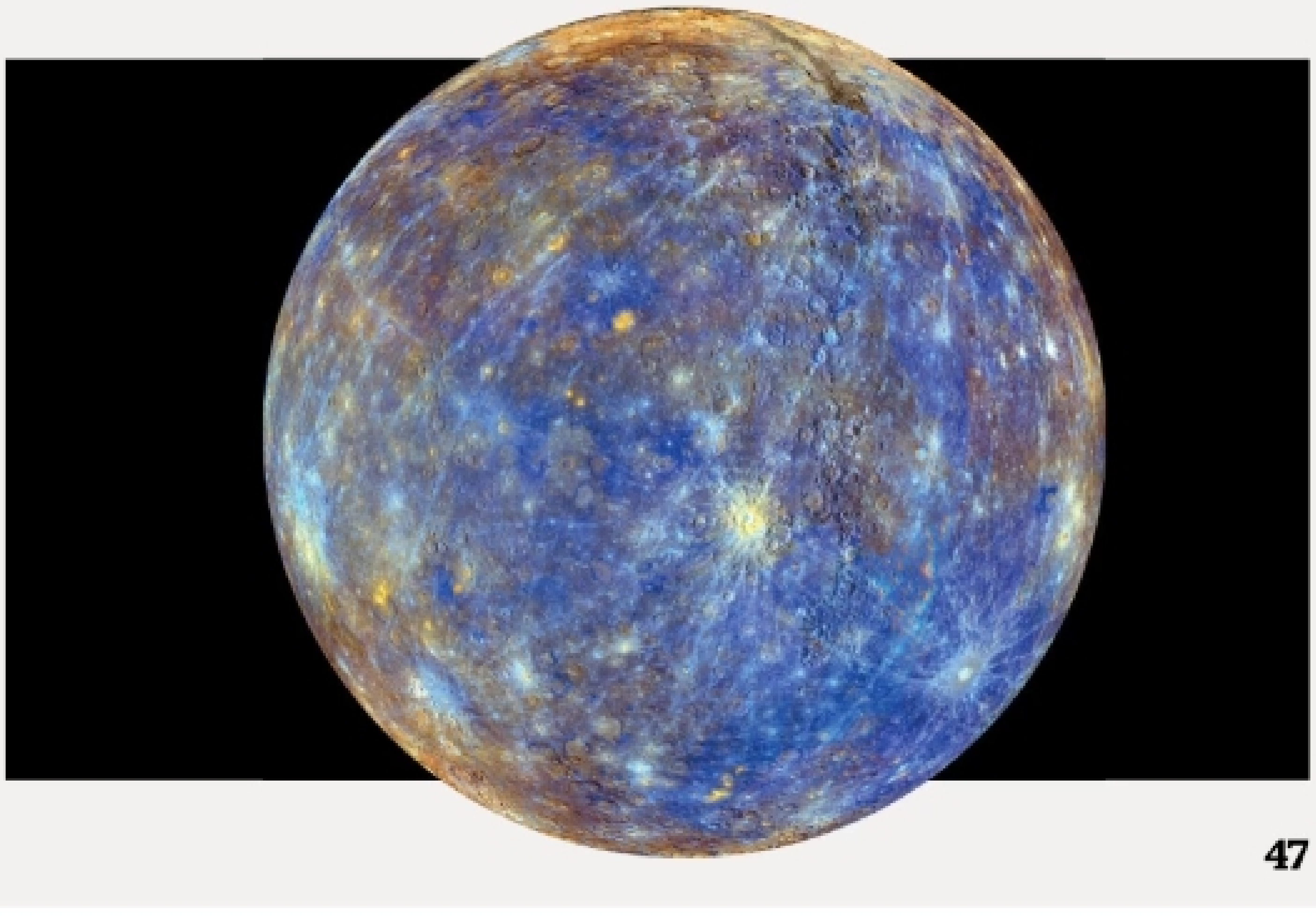
What is the surface of Mercury like?

Mercury is covered in craters, volcanic planes and holes ripped in the ground by violent volcanic explosions, violent events and more passive processes where the surface is just dissipating away somehow. We need to get this mapped. Half the planet was mapped in the late-1970s by the Mariner 10 mission, but we've got something that looks better than black-and-white imagery. We've now got a whole planet as seen by NASA's MESSENGER. But the MESSENGER team didn't undertake the job of making new geological maps of the planet. With our mission coming up, we're using the MESSENGER data to make geological maps because we want to understand the context of all our observations.

What do these maps look like?

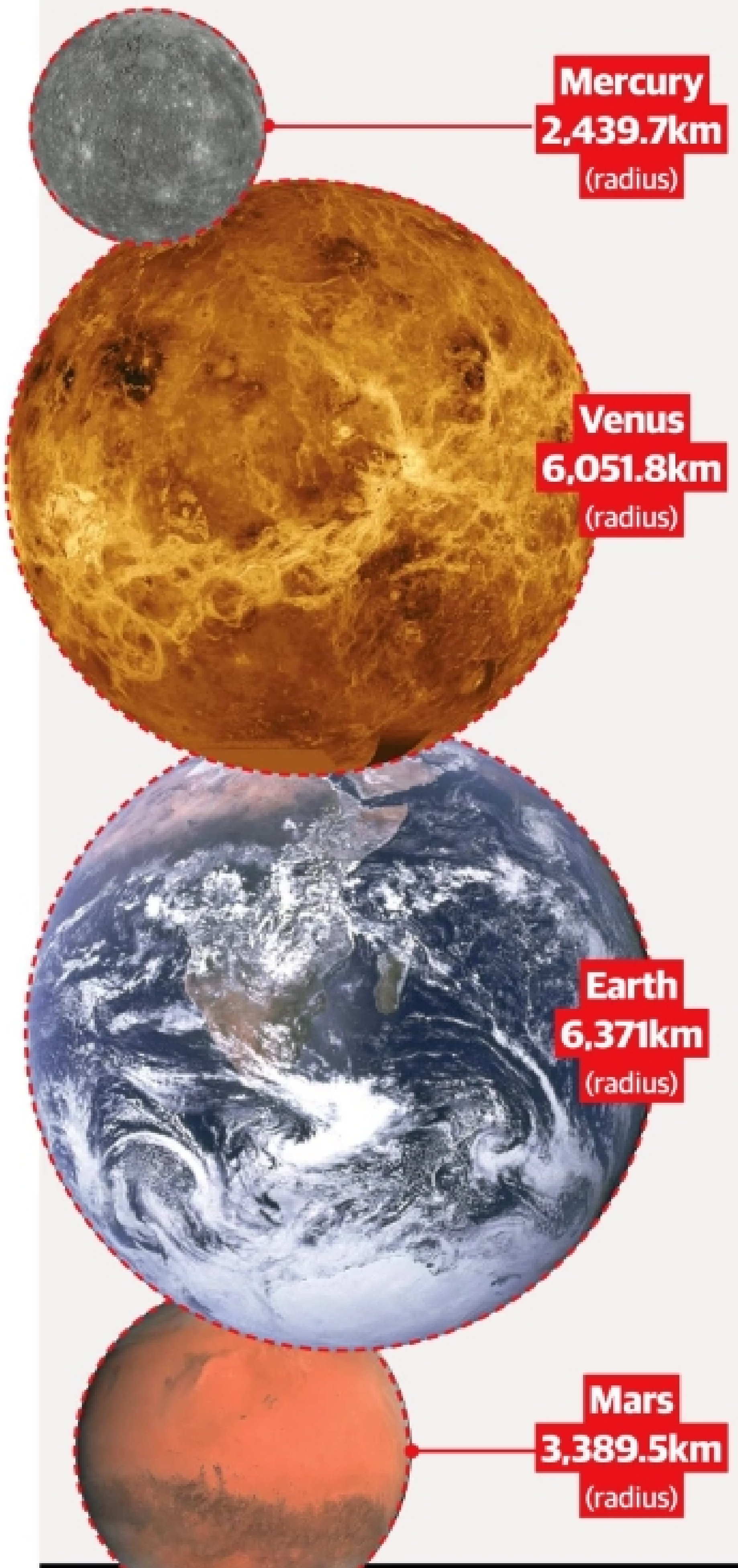
There are geological maps, or what we call a 'morphostratigraphy map'. The pale-brown areas indicate the smoothest plains, and they're smooth because they're young and there hasn't been time for many craters to accumulate. The mid-brown and the dark brown are progressively older classes of surface. The older they are, the rougher they are, because more craters have occurred. Then you map the individual craters more than 20 kilometres (12 miles) in size and distinguish them by age. The youngest craters sometimes have rays coming out from them and the ejecta is very prominent; you can see the burying of the old terrain and the craters look very fresh. The older craters are partly buried by younger events and they're more degraded with age. We've also broken it down to five degradation classes to try and work out the age relationships.

There have been topographic maps that have just come out from the stereo imaging or the laser altimetry that's been done. But here [at the OU] we're interpreting it as a geologist and identifying different surfaces and then saying which is older than which – let's get the layering worked out or the sequence of events worked out. When you have a geological map like that with the relative ages of surfaces, and then you get a new mission there and it says, "Hey! Over this area here it's high sulphur and low calcium, but over there it's the other way around," we can go straight to the map and say, "Wow! So that's the oldest stuff that's high



Right: This colourful view of Mercury, taken by MESSENGER, flaunts its chemical and mineral composition

© NASA



sulphur and low calcium." We can understand our observations because we've already done the best geological mapping we can.

How does the presence of craters on Mercury relate to the planet's age or past volcanic activity?

The craters we're dealing with are usually impact craters, and you can recognise them as they're almost exactly circular, produced by the shock of an impact. This is because impacts occur at Mercury at tens of kilometres per second. That shockwave radiates out from the point of impact, which is almost always circular with circular ejected patterns. The surface that's been there for 4 billion years is going to be absolutely covered in craters.

You can see that a surface that has a small number of craters superimposed is younger. But on some of these larger plains you can see the older craters that were flooded by the lava still visible, because they were flooded but not buried at such depths that all trace has been lost. You can see these ghost craters where there are traces of circular features.

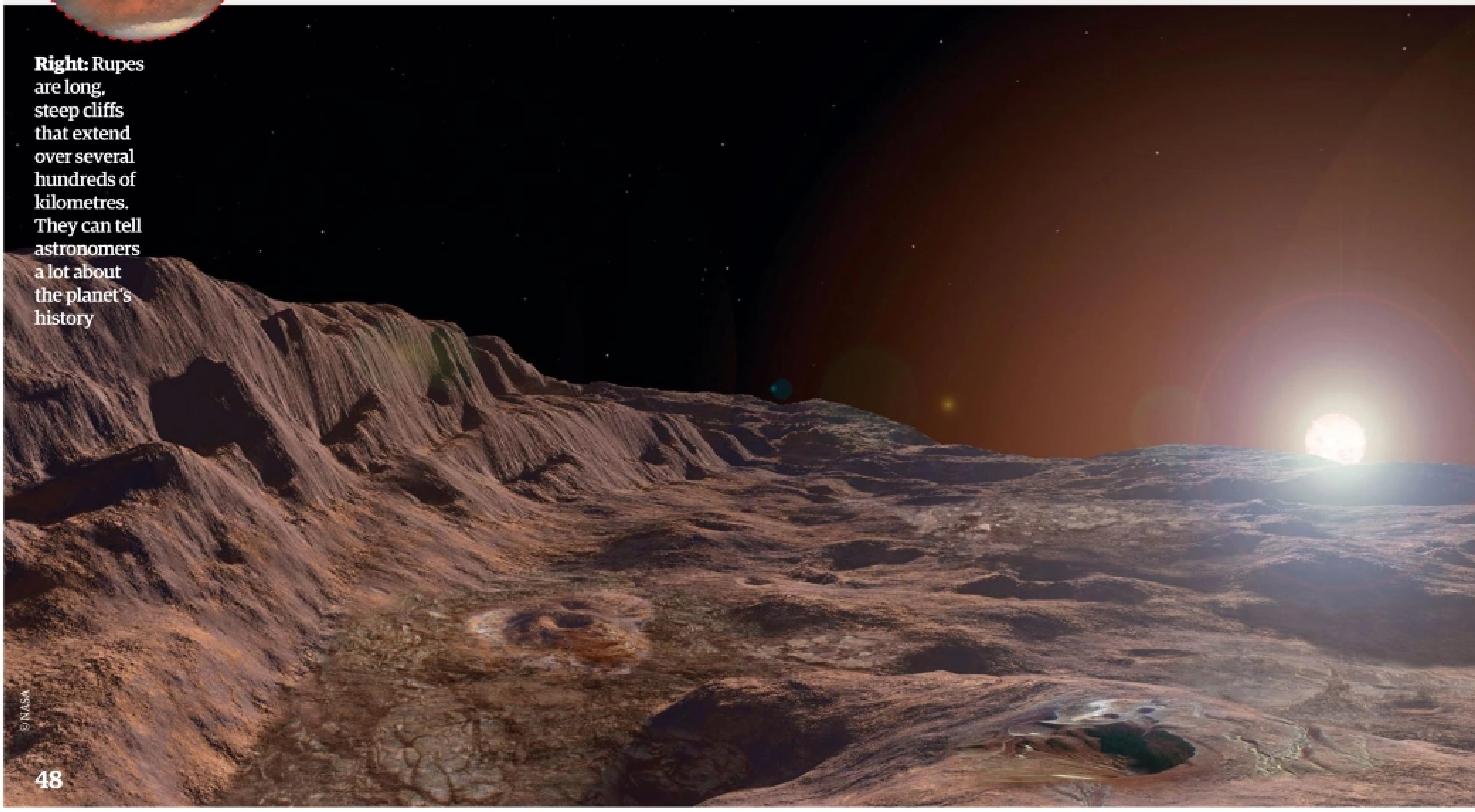
And then volcanically, there was also a series of explosive volcanic eruptions where holes were ripped in the ground. For example, there's a 30-kilometre (19-mile) wide, three-kilometre (1.9-mile) deep hole that was ripped out. Probably not in a single eruption, but a series of eruptions. And each time it went boom, it flung out a plume of material which just fell back to the surface. There's no atmosphere on Mercury, so it didn't start convecting like a volcanic eruption on Earth and just fell back down, and that's given us this 200- or 300-kilometre (120- or 190-mile) wide explosive eruption deposit on the surface.

You can work out the age of events, because the hole was ripped through material of a certain age, and the deposit is sitting on top of some of these young lava flows. To work out the age of events, it's a detective story. You see what's on top of what, what has ripped a hole through something else. There are geological faults on Mercury where parts of the surface have been thrust over features.

How does understanding Mercury help us understand Earth?

We've got four rocky planets in the Solar System: Mercury, Venus, Earth and Mars. They've all got factors in common. I mean, they've all got cores, which is where the dense, iron-rich material has gone, and they're surrounded by rock. But only Mercury and Earth have cores that are molten, and we know that because the Earth and Mercury have magnetic fields. You've got motion churning around, this electrically conductive fluid, which is what you need to generate a magnetic field. But it doesn't happen inside Mars or Venus. Why? We're not sure. Venus is almost the same size as Earth, and its core, as far as we can tell, is about the same size as Earth's core. It's completely solid; the core is not in motion. There is something strange going on there, but we don't understand why some planets generate their own magnetic fields and some don't.

Then there is how the surface behaves. Earth is the only rocky planet to have a rigid outer shell that can slide around on a very weak interior, hence plate tectonics. For example, the Atlantic Ocean is



Right: Rupes are long, steep cliffs that extend over several hundreds of kilometres. They can tell astronomers a lot about the planet's history

© NASA

getting wider and the floor of the Pacific Ocean is being pushed below South America. That kind of thing doesn't go on with any other rocky planet.

Each rocky planet has some features in common, but each has a very different history. We need to compare them. If we wanted to understand trees and how they work, you wouldn't just look at an oak tree. You need to look at a fir tree and a palm tree as well so you can understand how they all work. It's the same with the planets. You're not going to understand Earth if you don't understand how and why each of the three comparison bodies is different.

Would it be too simplistic to say that some features on Mercury were formed in a similar way to plate tectonics?

It's not that similar because in plate tectonics, when India crashed into Asia and started to go under it, it kept going under indefinitely, throwing up the Himalayas. Here the displacement is only five kilometres [three miles] or so. The faults on Mercury move a little way and then they grind to a halt, because Mercury's surface is not mobile. On Earth, plates are sliding around continuously. The features on Earth [move around a lot] because the planet is cooling down, and therefore contracting thermally. It's the effects of thermal contraction that's driving the thrust movement at the surface.

You're not going to get 1,000 kilometres [621 miles] worth of displacement [on Mercury], one slab over another, because the planet is not shrinking now. The shrinkage of Earth doesn't really get manifested because it's completely outpaced, but the whole idea of plates moving around and some sliding underneath each other, it's because of tectonic processes. It's the same kind of fault displacement [on Mercury], except the total amount of movement on it is much less.

Why have there only been two missions to Mercury so far?

I guess it didn't look that exciting. When Mariner 10 went there in the 1970s, it looked a bit Moon-like because it's covered in craters, but there are very important differences between Mercury and the Moon. However, it's less exciting than Mars, where it's had water flowing on the surface and there might be life, and less exciting than Venus, which is the Earth's twin except it evolved very differently.

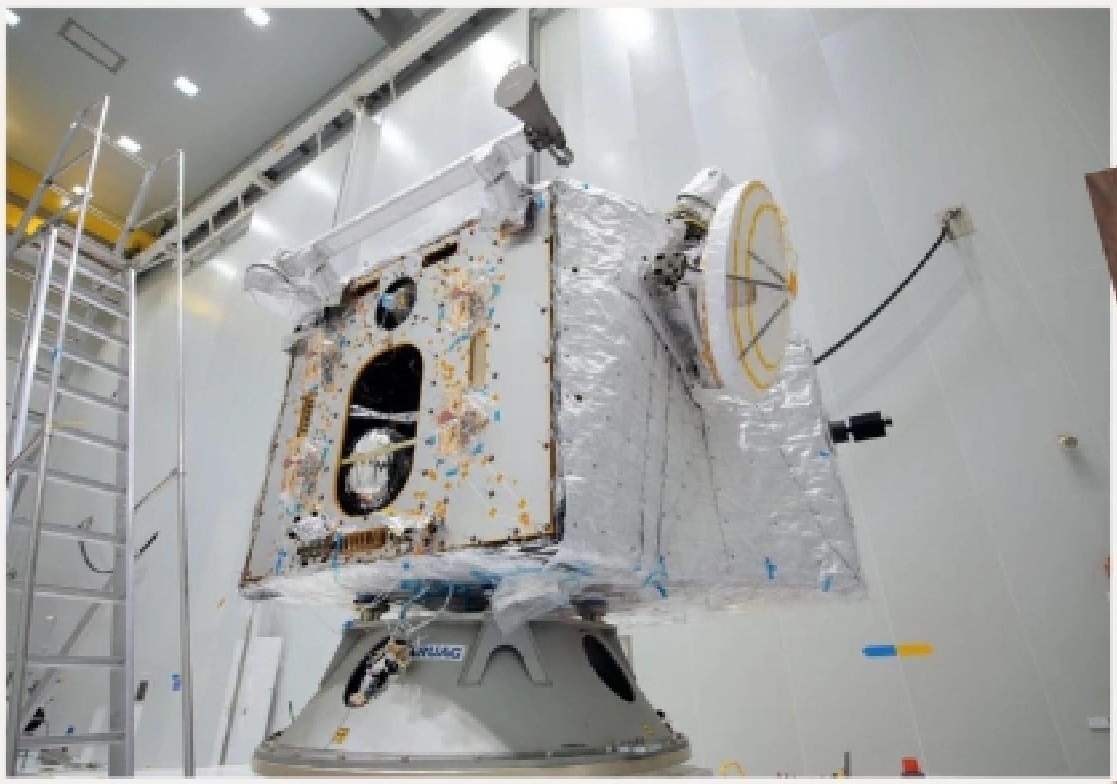
Although you can fly past Mercury relatively easily, if you wanted to send a spacecraft and whiz by it, once you've gone by you've gone by. The tricky thing is to get captured into orbit. That's very difficult at Mercury, because the changing velocity you need to be captured into orbit is very, very great. This is because if you send a spacecraft towards Mercury, you're basically falling towards the Sun, and the Sun's gravity will grab a hold of you and make you go faster and faster and faster, so when you get to Mercury, you're going far too fast to stop. It would just swing by the planet and disappear.

The trick that MESSENGER did, and the trick that BepiColombo will do, is to find a way to slow down so you get to Mercury going slowly enough to be captured into orbit. Both space probes had Venus flybys and then a series of Mercury flybys, and each flyby slows you down. We've got six or seven flybys for BepiColombo. On the seventh or eighth approach to Mercury, the spacecraft is going slowly enough that it can just use a small amount of fuel and get captured into orbit.

How have these previous missions shaped the science goals of BepiColombo?

I think Mercury has turned out to be far more interesting than we suspected before MESSENGER got there. For example, the explosive volcanism we didn't expect, or the recent hollows, places where the surface is patchy and stuff has been dissipating away into space. These regions dissipate at a very slow rate, millimetres per thousand years or something, but that's still young in terms of the Solar System. These are actively growing patches, but we don't know why. We don't know what's being lost, except it's got to be volatiles somehow. But is it sublimation like when you warm up dry ice and it just turns to vapour? Or is it breaking chemical bonds? Photons can break chemical bonds, micrometeorites can break chemical bonds and charged particles from solar wind can break chemical bonds. Any of those three could be attacking the surface and just helping it strip away to space, and that could be the source of some of the sodium in Mercury's exosphere.

The science goals of BepiColombo have been rewritten. We still want to understand how Mercury formed and so on. How it got so much iron, but has so little rock. And now we want to know how you couple that with being rich in volatiles. What are the volatiles that are being lost, and how has it hung on to them? Especially as these volatiles seem to have lost so much rock to give it a small amount of rock on a large core. It's a totally puzzling planet and I'm glad we're going!



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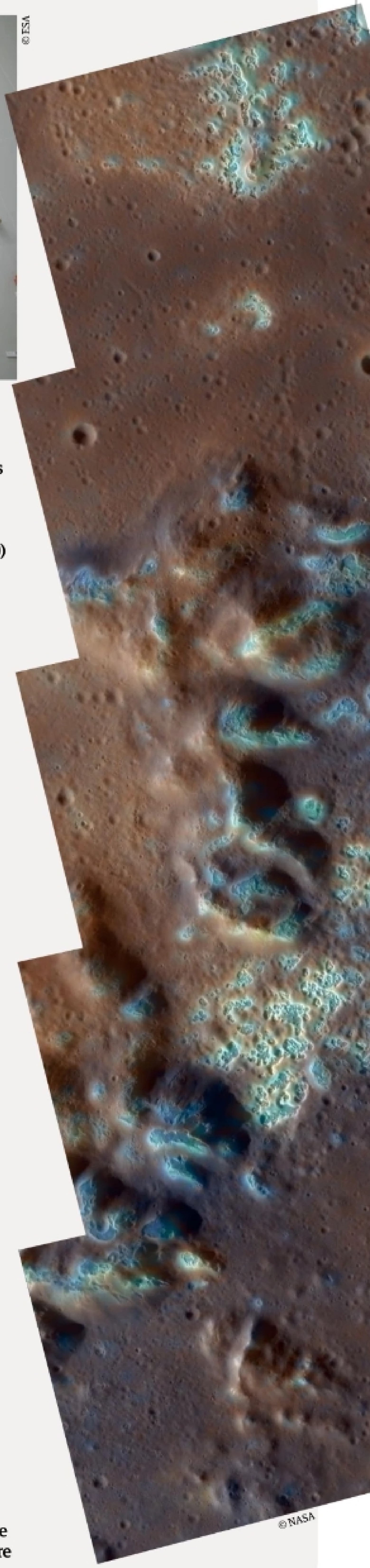
Above: The MIXS instrument is packed into the Mercury Planetary Orbiter (MPO)



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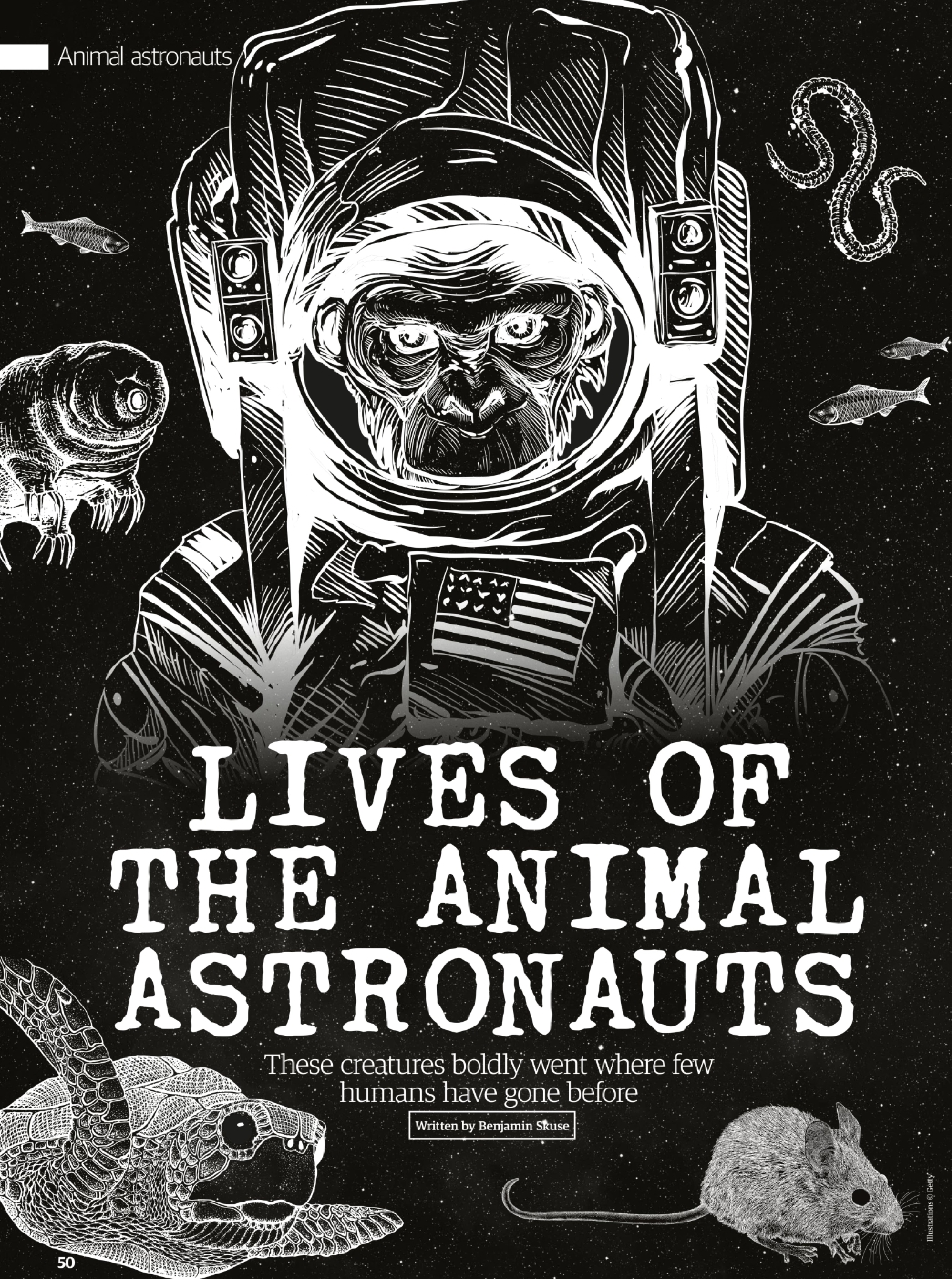
Right: The light blue, rounded depressions on the surface of Mercury are the 'hollows'



LIVES OF THE ANIMAL ASTRONAUTS

These creatures boldly went where few humans have gone before

Written by Benjamin Skuse

Illustrations © Getty

Muttnik orbits Earth

Perished

In the mid-20th century, the USSR launched dozens of hardy stray dogs above Earth's atmosphere to test whether humans could handle the rigours of space. The most famous of these is Laika – the first living creature to go into orbit. Captured wandering the streets of Moscow, Laika – which means 'Barker' in Russian – was strapped into a tiny space dog safety module and launched aboard Sputnik 2. Though Soviet scientists never intended Laika to return to Earth alive, at the time they suggested she had survived in space for between four days and a week before dying peacefully. It was later revealed in 2002 that her demise had been rather more harrowing. Laika had died from overheating and panic no more than seven hours after the mission began because a fan had failed. Her capsule orbited Earth 2,570 times before burning up in the atmosphere five months after blast off. In August 1960 a canine pair named Belka, or 'Squirrel', and Strelka, or 'Little Arrow' – joined by a rabbit, 42 mice and two rats – were strapped into Sputnik 5. These animals came to a less grisly end, launching into space and safely returning unharmed. Eight months later cosmonaut Yuri Gagarin famously followed in their pawsteps. Strelka went on to have six puppies, one of which – named Pushinka, or 'Fluffy' – was given to US president John F. Kennedy in 1961 by Soviet premier Nikita Khrushchev. Pushinka had four puppies with one of Kennedy's dogs, which the president affectionately referred to as pupniks.

3 November 1957/162 days

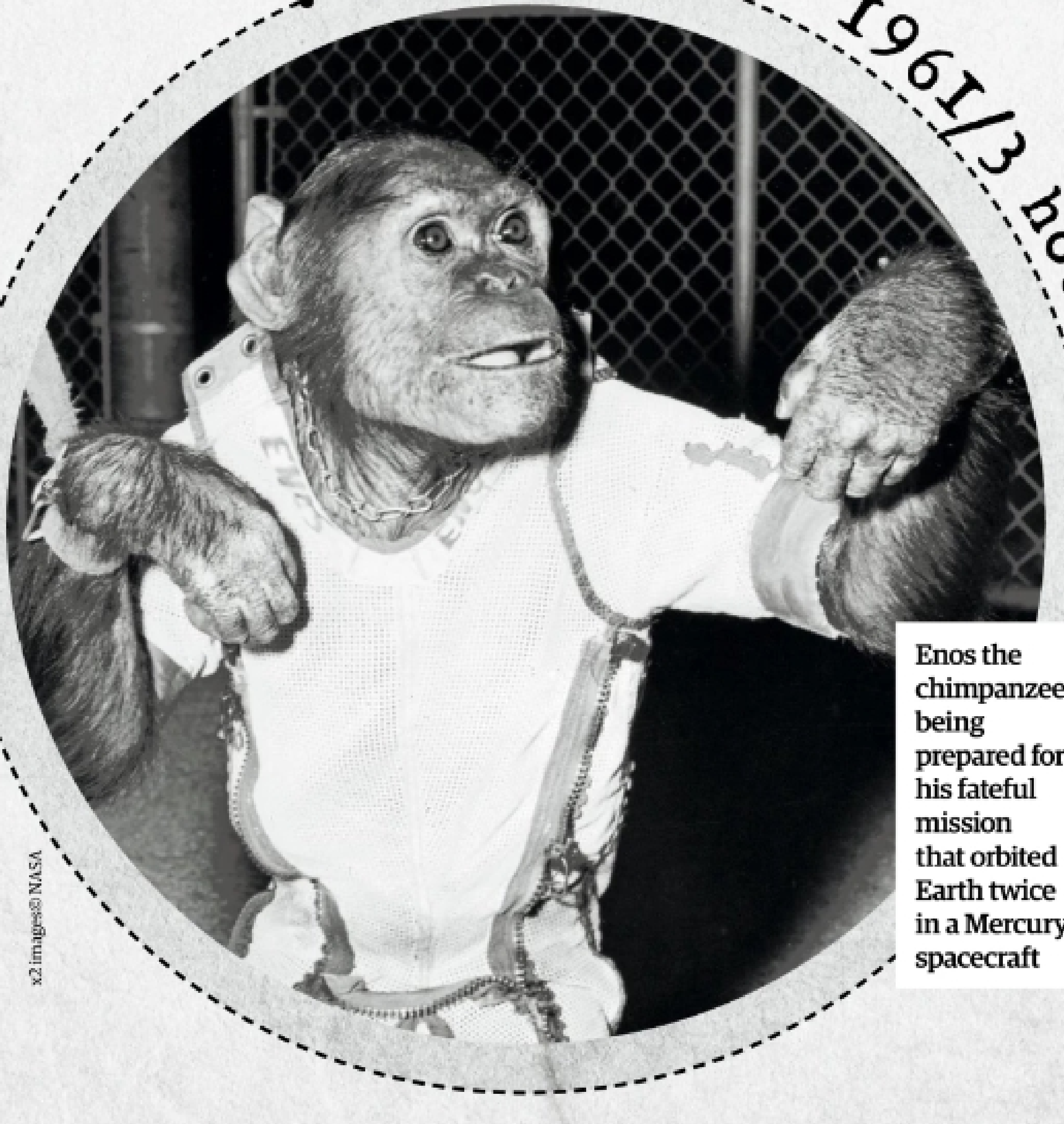
Laika the dog was the first living creature to orbit the Earth

© Sovfoto / Getty

Enos' agonising spaceflight

Survived

Enos was not the first primate in space – that accolade went to Ham earlier in 1961. He was not even the first hominid to orbit the Earth, also pipped to that distinction in 1961 by cosmonauts Yuri Gagarin and Gherman Titov. His spaceflight was simply intended to test equipment and procedures before risking a NASA astronaut. Enos' 1,263 hours of training for the flight included 'avoidance conditioning', during which electric shocks were administered to the soles of his feet if he responded incorrectly to simple tasks. This training aimed to get Enos to pull one of three levers in order to pick the odd one out from three presented shapes. In space, Enos began well during his first battery of tests. However, at the start of the second, the central lever malfunctioned. As a result, Enos was subjected to 76 unwarranted shocks. During the second orbit of an intended three, the flight encountered further problems. Alongside faulty equipment causing Enos' body temperature to rise, a stuck thruster was haemorrhaging fuel. This prompted NASA to terminate the flight early. Though an uneventful re-entry and landing, the stuck thruster caused the capsule to touch down hundreds of kilometres from where it should have. This meant Enos was stuck inside for 3 hours and 20 minutes. By the time he was extracted, Enos had broken through the protective belly panel, stripped off most of his physiological sensors and had forcibly and undoubtedly painfully removed his catheter while the balloon was still inflated. A little less than a year later, Enos died of dysentery – a sad end to an unlucky space chimp.



29 November 1961/3 hours

Enos the chimpanzee being prepared for his fateful mission that orbited Earth twice in a Mercury spacecraft

x2 images © NASA

The one and only space cat

Survived

A stray cat plucked from the streets of Paris became the first and only feline sent into space. The French had previously launched three rats into space and wanted to upgrade to larger mammals to study how they responded to weightlessness. To this end, researchers captured 14 cats to train for the journey into space. These would-be feline astronauts were subjected to surgery to implant electrodes in their brains, and testing which included compression chambers and centrifuges. In the end Félicette - a petite tuxedo cat - was chosen for the mission - she was not a late replacement for a male cat called Felix who had escaped, as has been widely misreported. Aboard a Véronique AGI sounding rocket launched from a base in the Sahara Desert, she flew 157 kilometres (97.5 miles) above Earth and spent several minutes in zero gravity, all while scientists monitored her progress via the electrodes implanted in her brain. Félicette survived her trip to space and her return to Earth. Sadly, after living for two to three months back on Earth, she was put down so her brain could be studied. A second and final feline was launched towards space less than two weeks later, but that rocket failed on takeoff, leading to the loss of its furry crew. Thanks to a Kickstarter campaign raising about £43,000 ($57,000), Félicette was recently commemorated when a bronze statue honouring the one and only space cat was unveiled at the International Space University in Strasbourg, France.

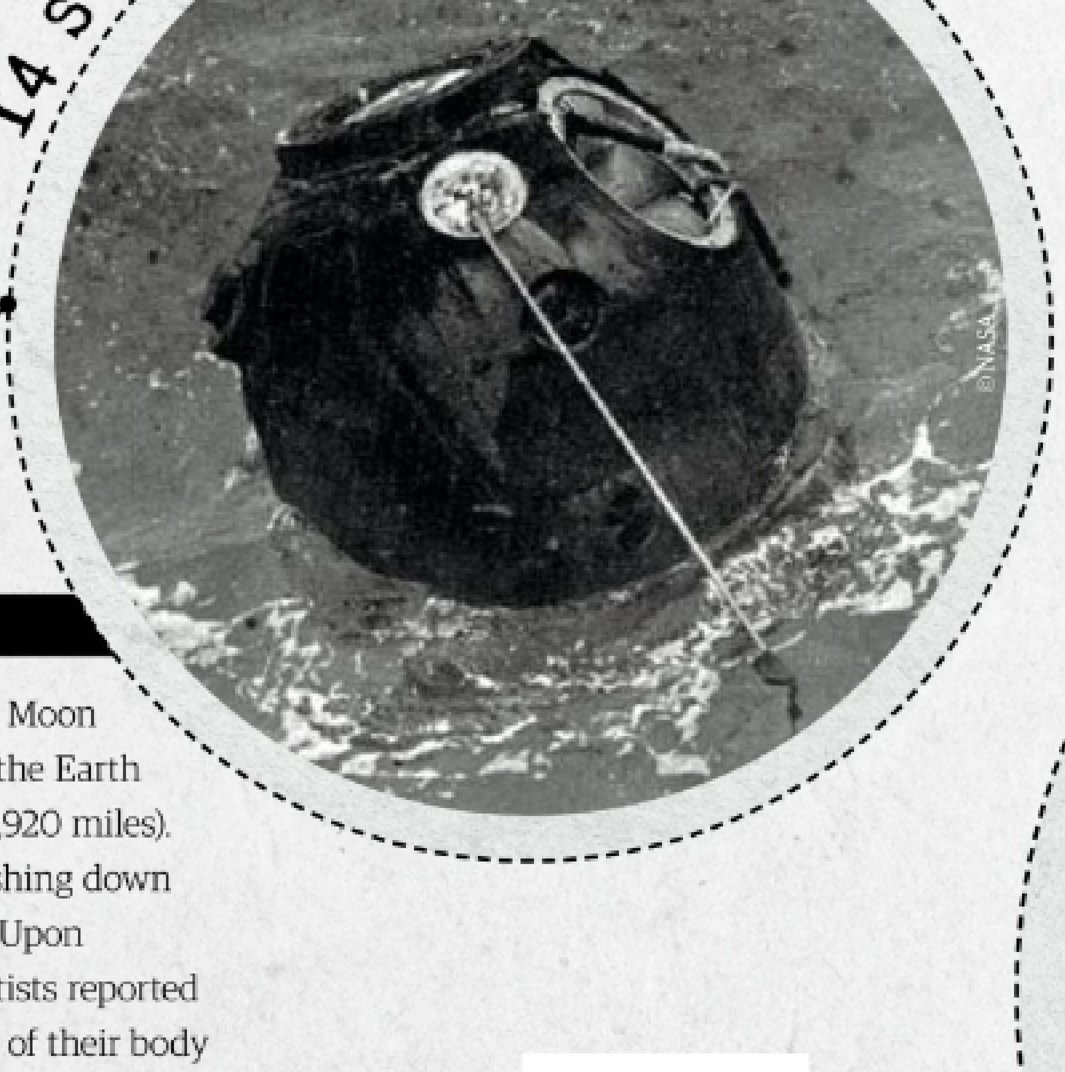
Félicette is the one and only feline to have ever successfully ventured into space

© Hulton Deutsch / Getty

18 October 1963 / 13 minutes

> “A stray cat from the streets of Paris became the first and only feline sent into space”

14 September 1968/6.5 days



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Slow and steady wins the race

Survived

Bringing new meaning to Aesop's fable of *The Tortoise and the Hare*, in the race to the Moon between the US and USSR, it was two steppe tortoises who pipped the Apollo 8 crew in being the first vertebrates to successfully journey around our lunar companion. Launching from a modified Soyuz capsule in southern Kazakhstan, the unnamed tortoises - joined by mealworms, wine flies, plants, seeds, bacteria and other life, plus a 70 kilogram mannequin containing radiation detectors in the pilot's seat - were sent on a circumlunar trajectory, looping around the Moon but not orbiting it. During this time the Zond 5 spacecraft reached a closest distance of 1,950 kilometres (1,212 miles) from the Moon and took high-quality photographs of the Earth at a distance of 90,000 kilometres (55,920 miles). All occupants survived their trip, splashing down in the Indian Ocean on 21 September. Upon assessment back on land, Soviet scientists reported that the tortoises had lost ten per cent of their body weight but otherwise seemed to be in good health, remaining active and showing no loss of appetite. Later half-shelled space pioneers include tortoises launched aboard Soyuz 20 on 17 November 1975. These tortoises set the record for the longest time any animal has spent outside Earth's atmosphere - 90.5 days.

Two tortoises pipped the Apollo 8 crew in being the first vertebrates to reach the Moon

The last lunar venturers

Four survived, one perished

7 December 1972/12.5 days

©NASA

The last three humans to visit the Moon were joined by five pocket mice held in tiny tubes

Even at the time Apollo 17 was a poignant mission, concluding the Apollo program and so signalling an end to human travel to the Moon for the foreseeable future. Yet the smallest occupants on the mission offered hope that humanity would soon be venturing even further afield, to Mars. This was because they had been implanted with radiation monitors under their scalps to study the effects of cosmic rays during long space travel. One of the animals died during the mission for unknown reasons, but the other four remained alive, circling around the Moon a record of 75 times in 147 hours and 43 minutes with astronaut Ron Evans, while Eugene Cernan and Harrison Schmitt were conducting the last moonwalks below. After their return to Earth the four remaining live mice were killed and dissected, and although lesions in the scalp and liver were detected they appeared to be unrelated to one another, and were not thought to be the result of cosmic rays. Furthermore, no significant damage was found to the mice's brains, eye retinas or other organs. Though inconclusive, scientists still learned a valuable lesson from the rodent experiment - that cosmic-ray experiments in particle accelerators on Earth could be useful, as they offered similar results to much more difficult space experiments. As a result, significant progress in radiobiology has been made in recent decades towards understanding the effects of cosmic rays on humans for future Mars missions.

23 October 2012/60 days

© JAXA

A student conceived the experiment that saw two orb-weaving spiders being sent to SkyLab

x3 Images © NASA

28 July 1973/59 days

Weaving a web of knowledge

Both perished

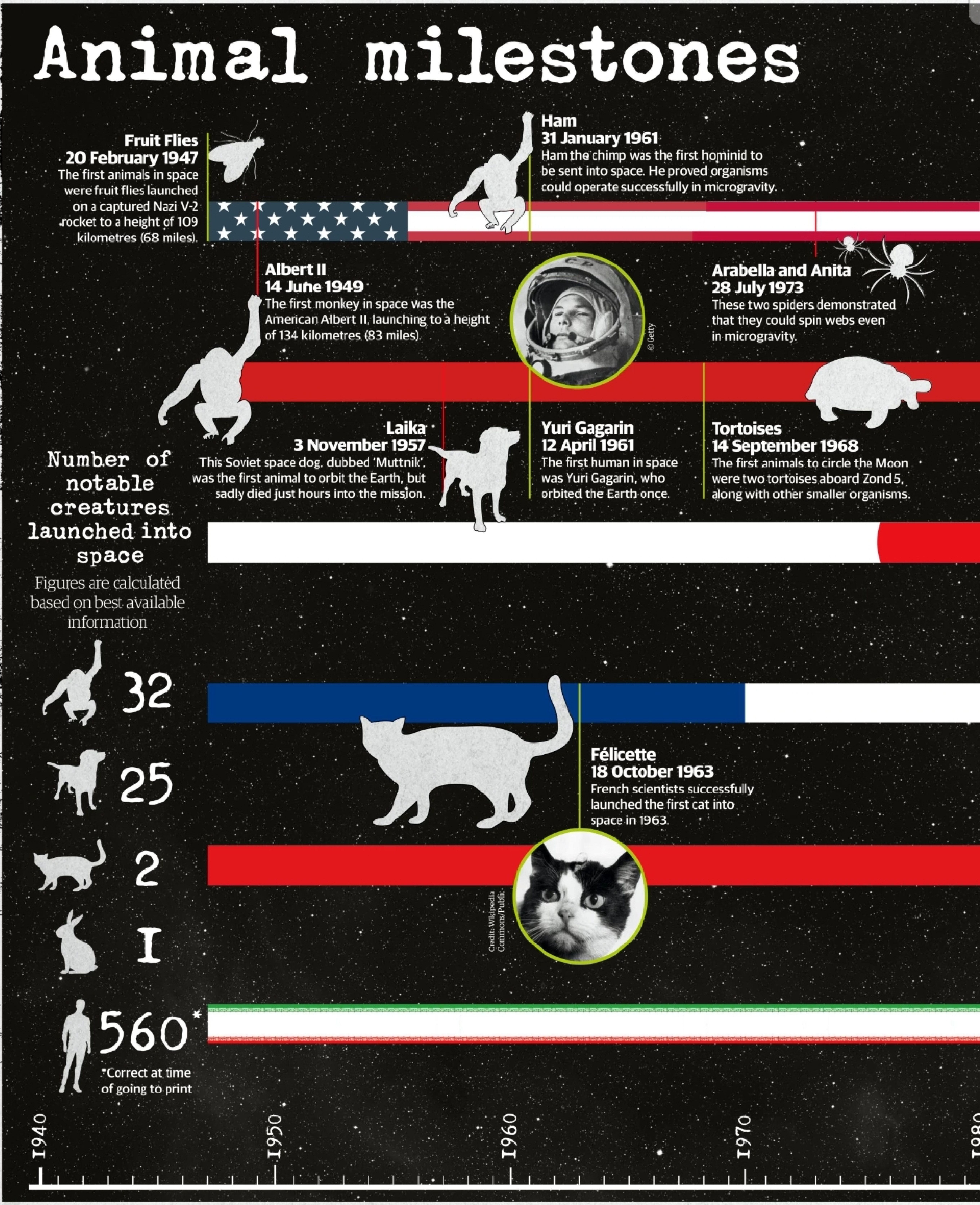
High-school student Judith Miles was the spark that led to the first spidernauts lifting off from Earth. She proposed an experiment to NASA called 'Web Formation in Zero Gravity', in which spiders would be released into a box where cameras would record their actions to assess how well they adapted to the absence of gravity. It was known that the geometrical structure of the web of an orb-weaving spider provides a good measure of the condition of its central nervous system. And it was thought that since spiders sense their own weight to judge how thick to weave their web, and use both the wind and gravity to sense when to begin construction, the lack of gravity in space would pose some serious issues for the arachnids. NASA agreed to the idea, and in 1973 two garden spiders called Anita and Arabella along with the experimental apparatus flew aboard the Skylab 3 mission. Though their initial efforts were distinctly confused, both spiders managed to spin sensible webs by the end of the mission, even though they were slightly finer than on Earth. Though they both died from dehydration during their flight, Anita and Arabella are preserved at the Smithsonian Air and Space Museum in Washington, DC. More recently, in 2008 and 2011, orb-weaver spiders were selected for further web-spinning experiments aboard the International Space Station (ISS), and a red-back jumping spider named Nefertiti was sent to see if it could still hunt effectively in zero gravity. All spiders showed remarkable adaptability.

Space swimmers

Perished

Medaka - also known as Japanese rice fish - are ideal for laboratory experiments. Not only hardy and simple to rear, they also have transparent skin, making it easier for researchers to see what is going on inside their bodies. They have been a popular choice for marine experiments in space - carrying the distinction of having been the first vertebrate to successfully mate in orbit, with fry hatching on the Space Shuttle Columbia in 1994. When JAXA - the Japanese space agency - wanted to conduct an experiment to see how fish would respond to radiation impact, bone degradation and muscle wastage, medaka were the natural choice. The medaka reached the ISS in 2012, and were transferred to the station's Aquatic Habitat, a purpose-built aquarium with an automatic feeding system, water circulation system and LED lights to represent day and night. Results from this and subsequent experiments have been interesting. For humans it takes at least ten days for any space-related bone symptoms to be revealed, but the medaka started losing bone density almost immediately when they arrived in orbit. Scientists hope these experiments will shed light on the processes that govern how human bodies adapt to space as well as give new insights into bone-related human diseases like osteoporosis.

Animal milestones



Fruit Flies
20 February 1947
The first animals in space were fruit flies launched on a captured Nazi V-2 rocket to a height of 109 kilometres (68 miles).

Ham
31 January 1961
Ham the chimp was the first hominid to be sent into space. He proved organisms could operate successfully in microgravity.

Albert II
14 June 1949
The first monkey in space was the American Albert II, launching to a height of 134 kilometres (83 miles).

© Getty

Arabella and Anita
28 July 1973
These two spiders demonstrated that they could spin webs even in microgravity.

Laika
3 November 1957
This Soviet space dog, dubbed 'Muttnik', was the first animal to orbit the Earth, but sadly died just hours into the mission.

Yuri Gagarin
12 April 1961
The first human in space was Yuri Gagarin, who orbited the Earth once.

Tortoises
14 September 1968
The first animals to circle the Moon were two tortoises aboard Zond 5, along with other smaller organisms.

Number of notable creatures launched into space

Figures are calculated based on best available information

32

25

2

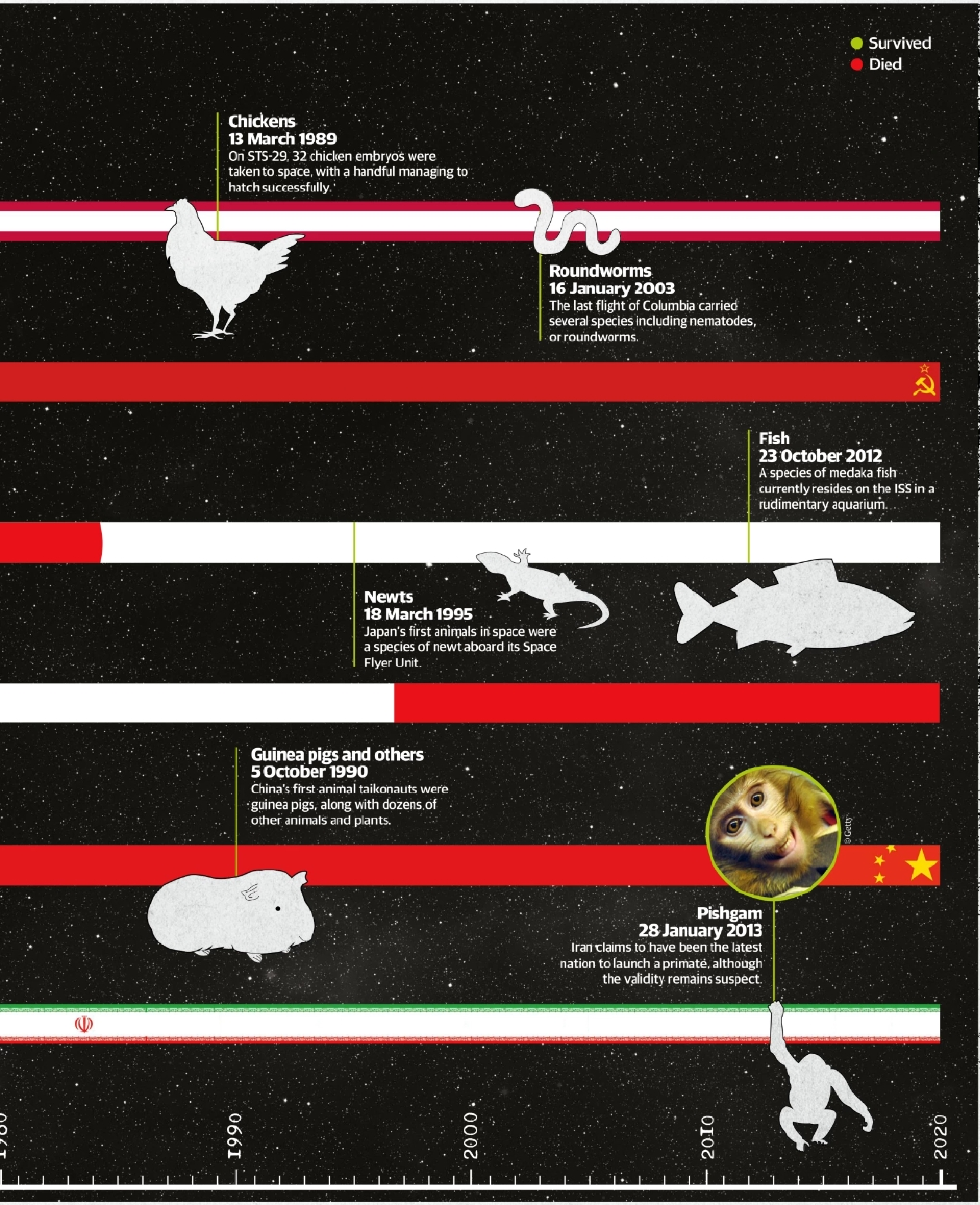
1

560*

*Correct at time of going to print

Félicette
18 October 1963
French scientists successfully launched the first cat into space in 1963.

Credit: Wikipedia Commons/Public



Chickens
13 March 1989
On STS-29, 32 chicken embryos were taken to space, with a handful managing to hatch successfully.

Roundworms
16 January 2003
The last flight of Columbia carried several species including nematodes, or roundworms.

Fish
23 October 2012
A species of medaka fish currently resides on the ISS in a rudimentary aquarium.

Newts
18 March 1995
Japan's first animals in space were a species of newt aboard its Space Flyer Unit.

Guinea pigs and others
5 October 1990
China's first animal taikonauts were guinea pigs, along with dozens of other animals and plants.

Pishgam
28 January 2013
Iran claims to have been the latest nation to launch a primate, although the validity remains suspect.

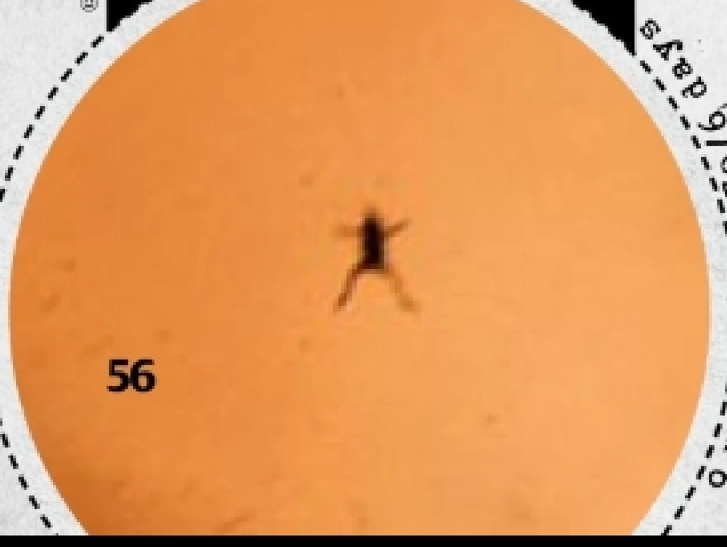
© Getty

Amphibian balancing act

Both perished

Two very different space adventurers were ready to spring into action in 1970, all in the name of understanding the effects of space travel and weightlessness on humans. The Orbiting Frog Otolith - 'otolith' refers to the frogs' inner-ear balance mechanism - spacecraft contained two bullfrogs that were in for a wild ride. After having surgery to implant electrodes into their thoraxes and vestibular systems - a part of the nervous system within the inner ear that helps to maintain balance - the frogs' nerves connecting their limb muscles were cut to prevent them from accidentally removing the electrodes. They were then placed in water for the duration of the flight to cushion them from vibrations and to keep them cool. Interestingly, after a bumpy first few days, by the last day of the six-day flight the frogs' vestibular systems had returned to normal, suggesting that they acclimatised to their space environment. Unfortunately for the frogs, they never returned to Earth. Many other frogs have been launched both before and after the Orbiting Frog Otolith experiment in the name of science.

© NASA



9 November 1970/6 days

A tragedy's only survivors

Survived

16 January 2003/16 days

© NASA

The Space Shuttle Columbia had served for roughly 22 years, completing 27 missions before its 2003 flight. On this fateful last mission, launch and orbit appeared to go well. However, the spacecraft and its seven-astronaut crew were tragically lost on re-entry to Earth's atmosphere. Caused by a hole that had been punctured in one of Columbia's wings during takeoff 16 days earlier, the disaster ultimately ended the Space Shuttle program. The initial seven-month investigation of the Columbia disaster yielded nearly 85,000 pieces of the spacecraft, including many of the 60 science experiments, some of which involved animals. Of the fish, insects, spiders, bees and silk worms that had been aboard, only the nematode worms survived. Hundreds of microscopic nematodes were found inside Petri dishes held in six canisters within a four-kilogram locker. It was the locker's robustness, reinforced specifically to protect the materials inside, that saved the nematodes. Yet the worms found were not the original survivors. As nematodes have a life cycle of seven to ten days, by the time they were discovered the worms were fourth- or fifth-generation descendants of the original spacefarers. From the amazing survival of the nematodes, astrobiologists learned that life can potentially travel between planets by natural means.

> "Astrobiologists learned that life can potentially travel between planets"

Hardiest animal on Earth, and in space

Survived

If you found a tardigrade floating in space, you would assume it was alien. Less than one-millimetre long, tardigrades are short, plump and puffy creatures, with four pairs of legs that each end in claws or sucking discs, and a tubular mouth ringed by teeth-like structures called stylets. Commonly known as 'water bears' or 'moss piglets', they are found in almost every environment imaginable on Earth, and are remarkably hardy. For this reason, in 2007 three groups of tardigrades were sent into space on the European Space Agency's Foton-M3 mission. During their trip the first group were exposed to the vacuum of outer space, the second group vacuum plus an unhealthy dose of solar radiation and the third vacuum plus full solar radiation exposure. Staggeringly, when returned to Earth and rehydrated, the first group showed no signs of damage. The two groups exposed to solar radiation fared worse, but even in the group exposed to a full dose of solar radiation, three tardigrades were successfully reanimated, making them the first animals to survive in outer space. It is for this reason some people believe tardigrades are alive on the Moon - in April 2019, Israeli spacecraft Beresheet crash-landed on the Moon carrying thousands of the tiny creatures.

14 September 2007/12 days

Tardigrades are indisputably the hardiest creatures on Earth and in space

Source: Wikipedia commons
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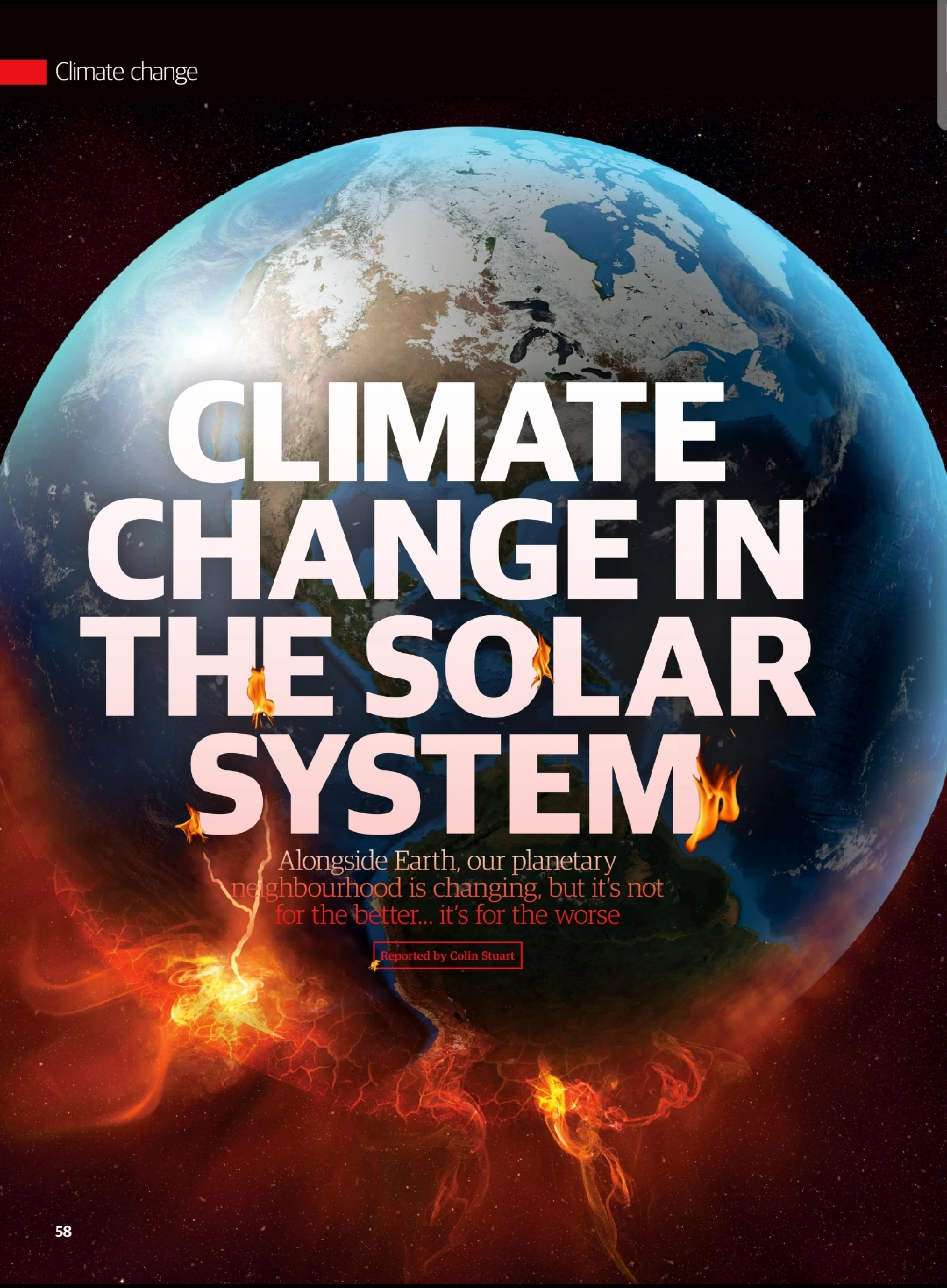


CLIMATE CHANGE IN THE SOLAR SYSTEM

Alongside Earth, our planetary neighbourhood is changing, but it's not for the better… it's for the worse

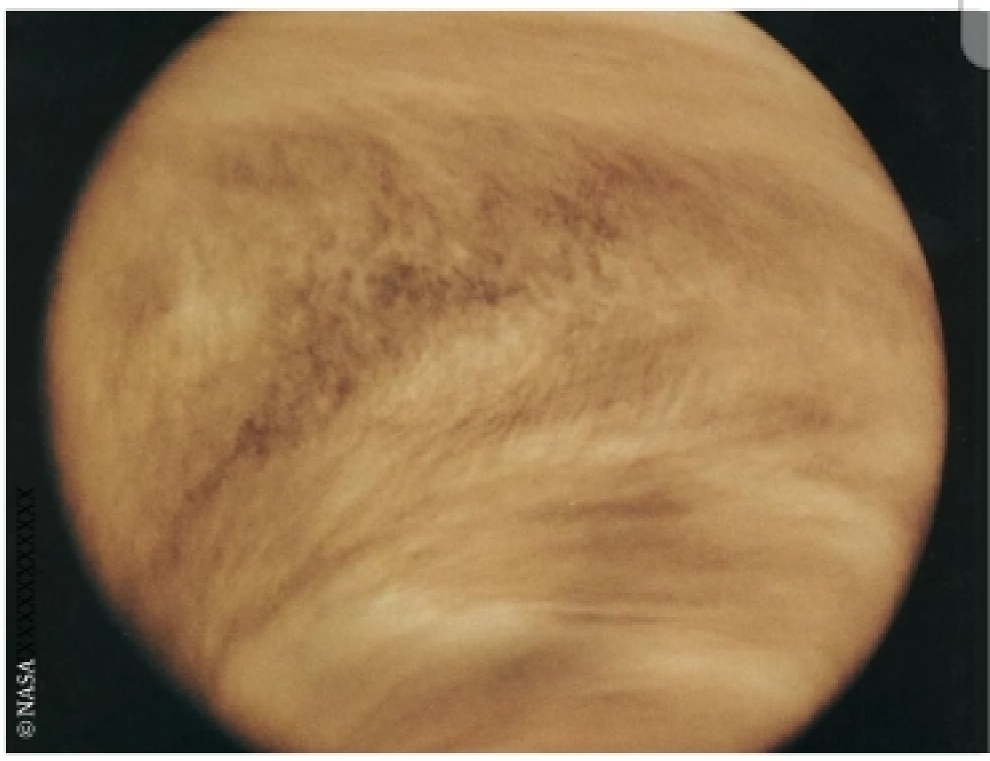
Reported by Colin Stuart

It's no secret that Earth is in trouble, and it is largely our fault. Since the Industrial Revolution we have been pumping so much carbon dioxide and other greenhouse gases into the atmosphere that our planet is rapidly warming. The race is on to keep the rise to under 1.5 degrees Celsius (2.7 degrees Fahrenheit), but it is a target we are predicted to miss. The consequences could be dire: rising sea levels, water shortages, increased migration and the possibility of more frequent wars as we battle each other for resources.

It could turn out to be the greatest foe we have ever faced, and it is largely of our own making, yet there is still time to turn things around. Public awareness of the issue has never been higher, and governments and individuals alike are slowly starting to wake up to their responsibilities – but will it all be too late? Part of the trouble is that the climate of a planet is an incredibly complex system with a lot of moving parts. Throughout its history Earth has warmed and cooled all on its own, alternating between ice ages and more temperate phases. How do we tease out our contribution from these background ups and downs? According to Dr Nicholas Attree, a research fellow at the University of Stirling, we could do a lot worse than to look at our neighbours. "What we see on Earth is natural climate cycles, plus human influence," he says. "Looking at the cycles of other planets means we can better understand our cycles and better understand our influence."

Attree has been looking closely at Mars' past climate. It is the most explored planet in the Solar System, with a host of active rovers trawling the surface and satellites whizzing around it examining the ground from on high. We have discovered that, like Earth, Mars cycles through periods with different climatic conditions. The reason is simple: gravity. Unlike Earth, Mars has no large Moon for stability. Combine that with the fact it is closer to the Solar System's big boys – Jupiter and Saturn – and it gets bullied by its giant neighbours. Being pulled this way and that leads to a change in Mars' obliquity – the tilt of the axis on which it rotates. It also changes the shape of Mars' orbit over time, making is successively more and less circular.

The upshot is that the intensity of sunlight falling on Mars is constantly changing, but in a regular way. A single cycle lasts tens of thousands of years. Attree has been looking at whether these climatic mood swings could have left a detectable signature on Mars today. "During warmer periods there would be an increased heat flow under the Martian surface," he says. "We've modelled how that heat would build up over time." In November last year he published a prediction that NASA's InSight may be able to detect that excess heat. InSight landed on the Red Planet in November 2018 and is equipped with a self-hammering 'mole'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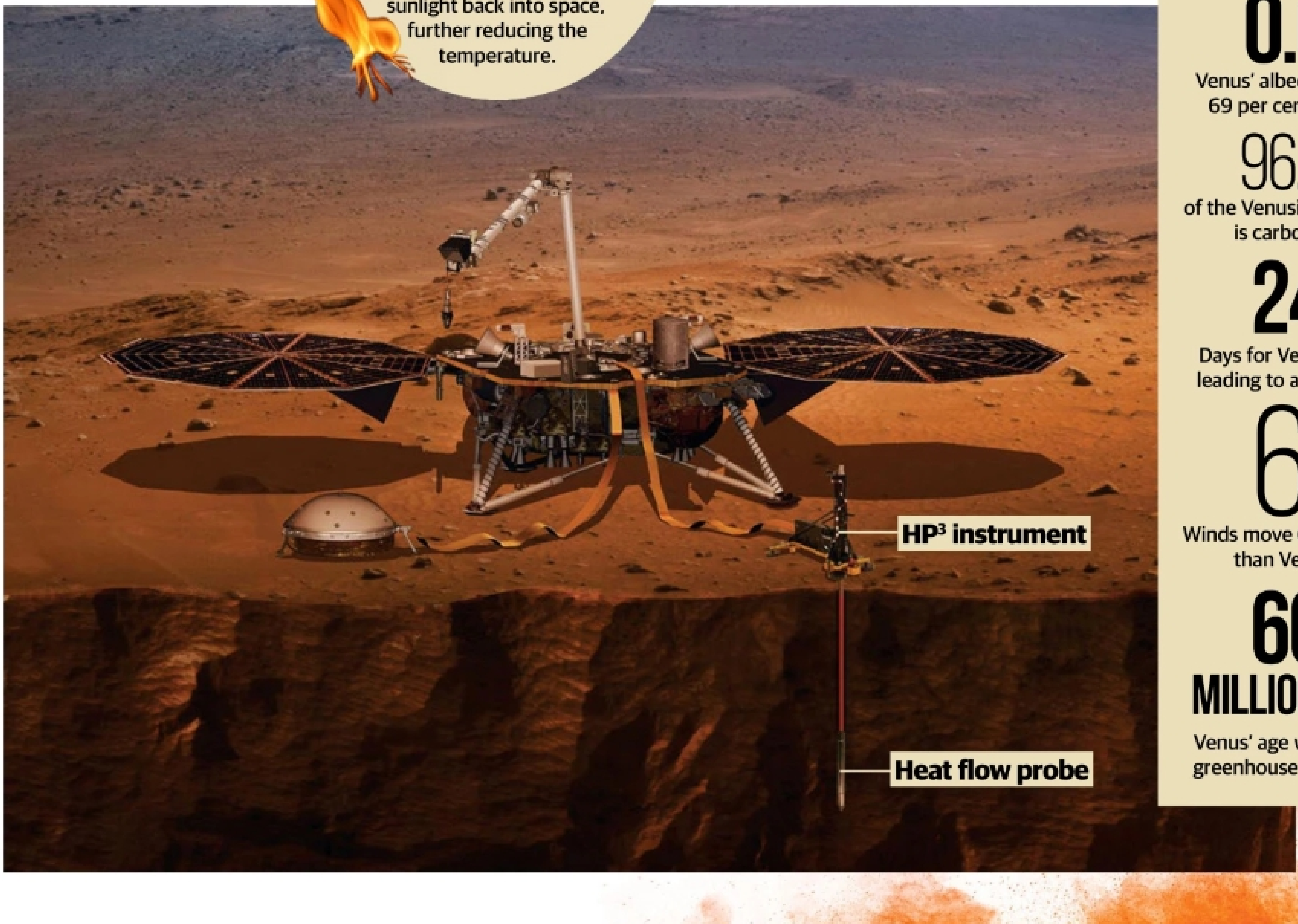
Above: The thick clouds on Venus prevent us seeing the surface in visible light

Below: The HP³ probe on NASA's InSight mission is measuring Mars' internal heat

A regular cycle of ice ages

Earth's tilt changes over time, leading to changing levels of solar energy hitting the planet. Ice coverage increases and the bright ice reflects more sunlight back into space, further reducing the temperature.



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VENUS BY THE NUMBERS

464°C
Average temperature – about twice as hot as an oven

92
Atmospheric pressure compared to Earth – same as being one kilometre (0.62 miles) underwater

0.69
Venus' albedo – it reflects 69 per cent of sunlight

96.5%
of the Venusian atmosphere is carbon dioxide

243
Days for Venus to rotate, leading to a static climate

60
Winds move 60-times faster than Venus spins

600 MILLION YEARS
Venus' age when runaway greenhouse effects began

© NASA

Left: Some researchers argue that Venus would have been a potentially habitable planet long ago

designed to burrow into the Martian dirt. Among its instruments is a thermometer – the Heat Flow and Physical Properties Package, or HP³, perfect for looking at Mars' sub-surface heat.

Unfortunately the mission has been beset with difficulties. On its first attempt the mole reached a depth of just 35 centimetres (13.8 inches) before getting stuck. Mission scientists are still trying to puzzle out the problem and see if it can get as deep as planned, but by their own admission it isn't looking promising. Detecting Attree's predicted excess now looks difficult. "We were only likely to find it if the instrument was functioning perfectly," he says. All is not lost, however. There is another way to keep track of Mars' past climate cycles: carbon dioxide. Today the gas that's causing us so many woes on Earth is the main constituent of the Martian atmosphere. Yet the air is so thin that the atmospheric pressure on Mars is just 0.6 per cent of Earth's. Carbon dioxide is also frozen into the Martian ice caps. When changes to Mars' orbit and tilt increase the Sun's intensity, the carbon dioxide ice sublimates – turns straight from a solid to gas – and carbon dioxide is added to the Martian atmosphere. When things turn colder, the gas is deposited back onto the ice caps. In the 1960s it was predicted that the atmospheric pressure on Mars cycles in this way, getting as low as four-times less than today's level and as high as double. Yet evidence to back this up has remained elusive. Then, in December 2019, a new study claimed to have found it at long last.

It all hinges on the layers of carbon dioxide dry ice and water ice on the planet's south pole. A kilometre (0.62 miles) deep, it contains as much carbon dioxide as currently exists in the entire atmosphere. Radar measurements from orbiting satellites suggest the cap is formed of alternating layers of dry and water ice. Dry ice trapped under water ice shouldn't be stable, yet it seems to persist.

THE CHANGING CLIMATE OF VENUS

According to research, our neighbour's environment has changed dramatically

STEP 1

Magma ocean

Just like the primitive Earth, early Venus was still largely molten as a result of the high-energy impacts that formed the planet in the first place. This led to a widespread ocean of magma (molten rock) across the planet, leading to very high temperatures.

STEP 2

Gas and steam

Impacts added additional material to Venus, including a significant amount of water. Coupled with the heat from the magma ocean and Venus' proximity to the Sun, an early atmosphere began to form around the planet, largely made of carbon dioxide and steam.

STEP 3

Cooling and condensing

Over time the number of impacts began to die away; the unbattered planet began to cool down and a solid crust formed on the surface. Steam started to condense out of the atmosphere and fall as rain, creating Venusian lakes, rivers and seas.

STEP 4

Vociferous volcanism

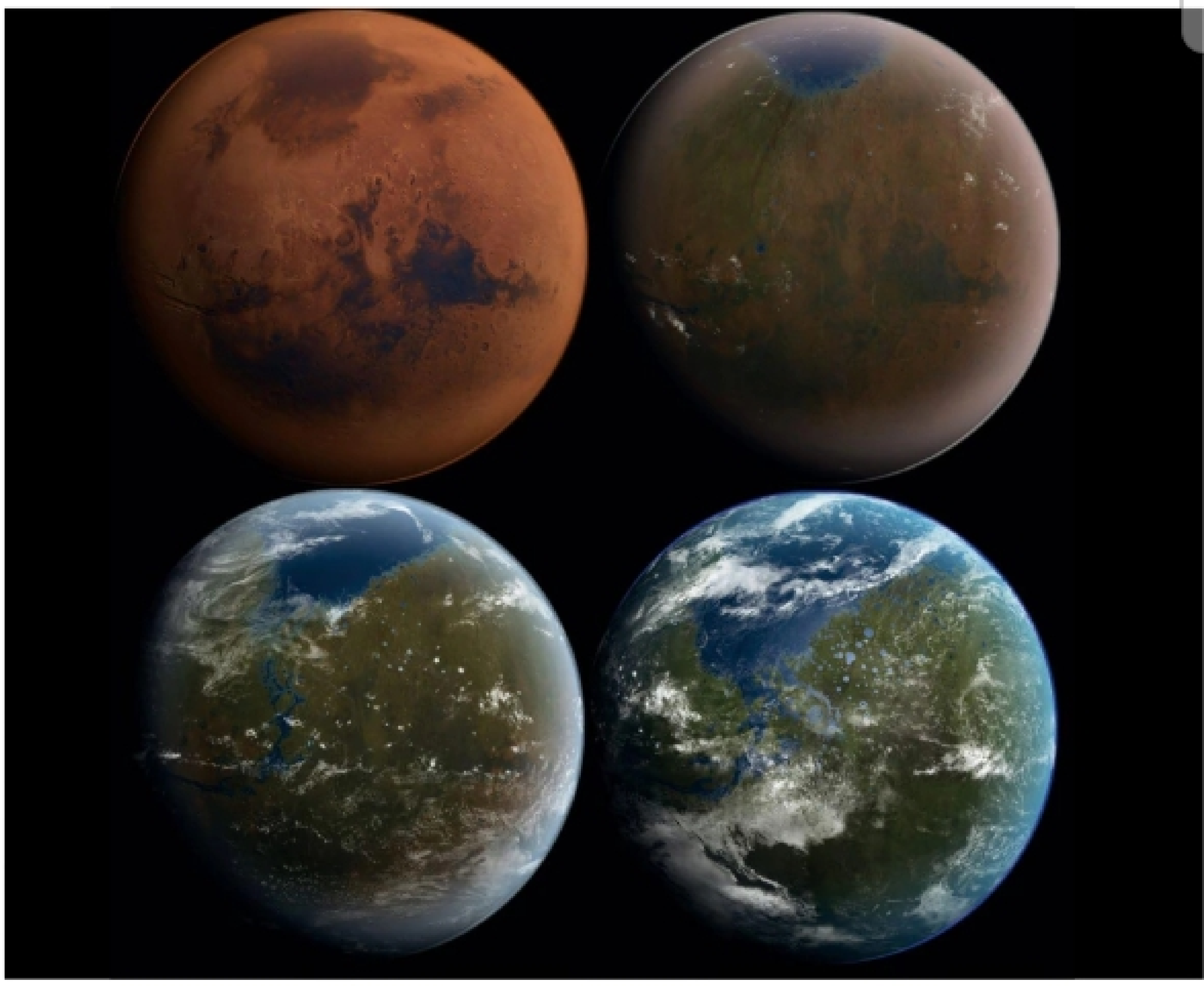
Deep inside the planet, under the crust, the magma ocean persisted. This led to wide-scale volcanism across Venus. Today we can still see these volcanoes, including the planet's tallest – Maat Mons. Eruptions added huge quantities of carbon dioxide back into the atmosphere.

STEP 5

Global warming

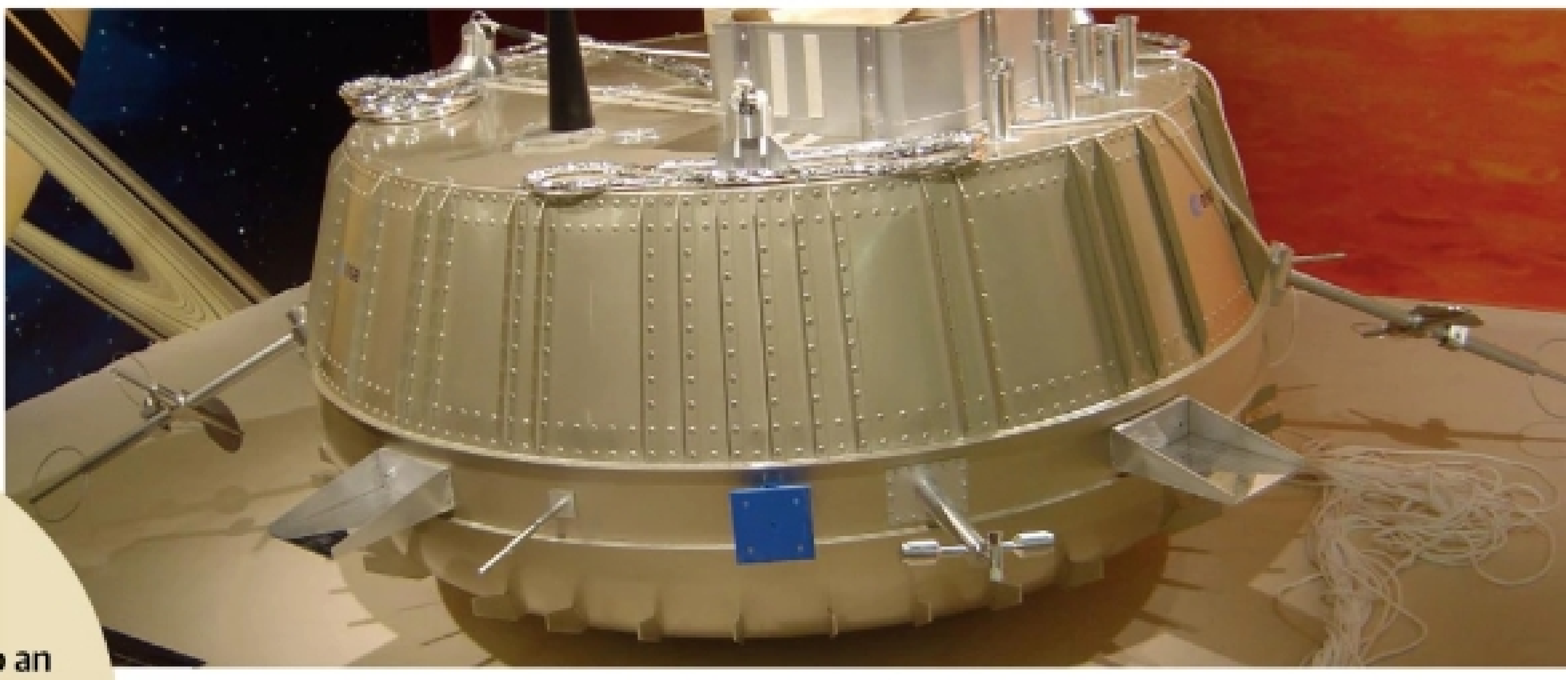
As we've discovered on Earth, carbon dioxide is a powerful greenhouse gas. It lets solar energy in, but makes it hard for it to escape. Over time this has raised the temperature on Venus, far beyond the boiling point of water. No lakes, rivers or seas remain.

© NASA



Source: Wikimpedia © Daein Ballard

Right: One day it may be possible to engineer Mars' climate to be more hospitable



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Below: The ESA's Huygens probe touched down on Saturn's largest moon Titan in 2005

Modelling by Peter Buhler, a planetary scientist at NASA's Jet Propulsion Laboratory, is attempting to explain its longevity. Each time Mars warms up, some of the dry ice remains trapped under the water ice. The carbon dioxide that does escape is eventually deposited back on top of the water ice when temperatures plummet. That leads to the layering we see. Studying these layers should allow researchers to more accurately construct a picture of Mars' climate stretching back billions of years to a time when the planet may have been habitable. Ultimately we may get a better answer to the question of whether there's ever been life on Mars.

According to Michael Way from NASA's Goddard Institute for Space Studies, it could also help work out where to land when planning future human missions to the Red Planet. "They'd definitely want to talk to the climate modellers," he says. "It could tell you where to place your settlements or where the sub-surface water is most likely to be." Way and his colleagues have been adapting NASA's model of Earth's climate and applying it to other bodies in the Solar System, including Mars. It's known as a general circulation model. "It combines factors such as ocean circulation, wind circulation, cloud dynamics and different types of cloud," Way says. "It also estimates how many photons of light enter our atmosphere and are absorbed or reflected." Porting this model over to other worlds is not an easy task. "Applying it to modern Mars is very challenging," he says. It should get easier with the passage of time as improvements in computing power allow more intricate models to run in a shorter amount of time.

What killed the dinosaurs?

It's famously attributed to an asteroid impact, which threw huge volumes of debris into the sky and blocked out the Sun. A rapid change followed which put pressure on the big lizards.

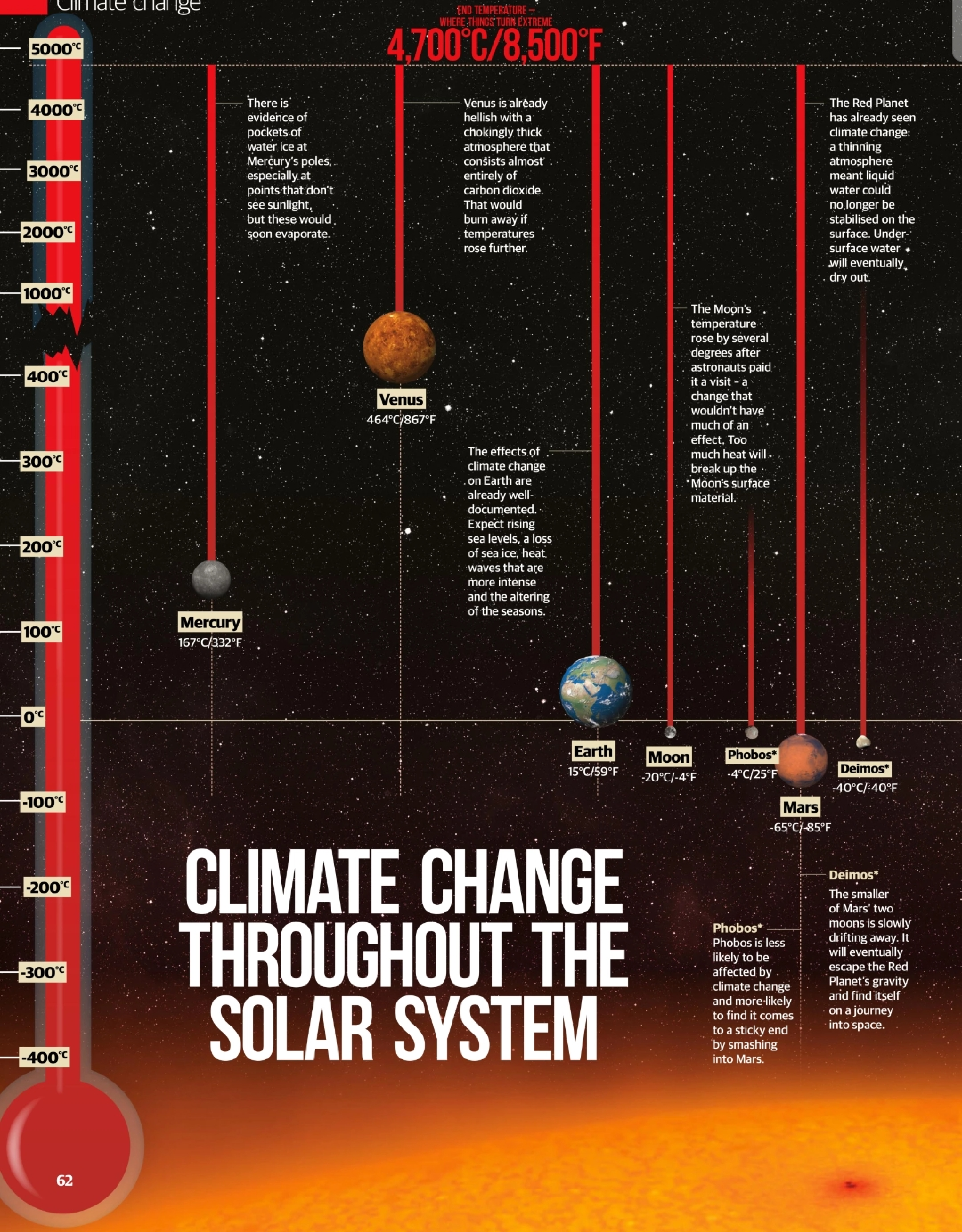
If Mars is hard, then modelling Venus' climate is even tougher. The world called Earth's 'twin' is an unforgiving hellhole. Thick clouds of carbon dioxide trap the Sun's heat, sending temperatures soaring beyond 400 degrees Celsius (752 degrees Fahrenheit). The atmospheric pressure is nearly one hundred times greater than Earth's and over 15,000-times higher than on Mars. That has severely restricted our ability to land space missions on Venus. Those that did make it to the surface succumbed very quickly to the mayhem. "We have very few data points for Venus," says Way. Unlike Mars you can't just run rovers around, taking lots of temperature measurements. "Our models struggle as a result," he says.

The models that have been devised so far point to two different possible climatic histories for Venus, depending on how long the planet's early magma ocean hung around. The rocky planets were formed when lumps of rock and metal called planetesimals smashed into one another with such ferocity that the solid materials melted. Being closer to the Sun, whose light was more intense at the time, combined with the presence of a hot magma ocean, created an atmosphere of steam and carbon dioxide. "The atmospheric pressure would have been one thousand times greater than the modern Earth," says Way. A molecule of water is H_2O – two atoms of hydrogen bonded to one atom of oxygen. On a hot Venus this bond would have been broken regularly. The hydrogen is lost to space and the oxygen becomes trapped inside the magma ocean. "If that's the case then Venus has been a dry, desiccated world for most of the last 4 billion years," says Way. The alternative is that the magma ocean was a much shorter lived phase. "Then it would have been cool enough to condense water into lakes, rivers and oceans," says Way. In other words, far more Earth-like than today. Perhaps the Solar System had two habitable planets at the same time.

If it's the latter then Venus has experienced a huge change in climate over the last 4 billion years, largely thanks to the role of carbon dioxide. Given our current climate predicament on Earth, is there anything we can learn from our neighbour? "It's a compelling idea," says Way, "but it is a difficult comparison to make." The driver of Venusian climate change is largely thought to have been large-scale volcanism dumping huge quantities of carbon dioxide into the atmosphere, far more than we've added to the Earth's since the Industrial Revolution. "Unlike Venus, the Earth will eventually adjust to this increase in carbon. We just may not be around to see it," Way says.

Along with Venus and Mars, Way and his colleagues have also secured funding to model the climate of Titan – Saturn's largest satellite and the only moon in the Solar System with a thick atmosphere. "Titan is interesting as the density of its atmosphere is only 1.5 times Earth's," Way says. "A lot of its climate dynamics are similar too." Part of the attraction of studying Titan is the wealth of data that came back from the Cassini mission

CLIMATE CHANGE THROUGHOUT THE SOLAR SYSTEM



There is evidence of pockets of water ice at Mercury's poles, especially at points that don't see sunlight, but these would soon evaporate.

Venus is already hellish with a chokingly thick atmosphere that consists almost entirely of carbon dioxide. That would burn away if temperatures rose further.

The effects of climate change on Earth are already well-documented. Expect rising sea levels, a loss of sea ice, heat waves that are more intense and the altering of the seasons.

The Moon's temperature rose by several degrees after astronauts paid it a visit – a change that wouldn't have much of an effect. Too much heat will break up the Moon's surface material.

The Red Planet has already seen climate change: a thinning atmosphere meant liquid water could no longer be stabilised on the surface. Under-surface water will eventually dry out.

Phobos*
Phobos is less likely to be affected by climate change and more likely to find it comes to a sticky end by smashing into Mars.

Deimos*
The smaller of Mars' two moons is slowly drifting away. It will eventually escape the Red Planet's gravity and find itself on a journey into space.

*Ganymede

There is no atmosphere to trap heat on Ganymede, but it has its own magnetic field thanks to past heating that melted ice and caused rock to sink inwards.

* Europa

The surface temperature of Europa is largely determined by its ability to retain the Sun's heat. Ice on its surface would be lost if the moon was heated though.

We know that our Sun will become a red giant in approximately 5 billion years time. By then it will have consumed the terrestrial planets, though some planetary material will assimilate with this gas giant.

* Titan

As its atmosphere has warmed in the past, pockets of liquid nitrogen may have exploded from the moon's crust. It suggests Titan – which sees liquid methane fill those craters – may be susceptible to climate change.

* Enceladus

Since it is mainly covered by fresh, clean ice, Enceladus will undoubtedly suffer should temperatures rise.

In the case of the Sun becoming larger and warmer, the rings of Saturn would end up being vaporised since they are made almost entirely of water ice.

* Ceres

The dwarf planet Ceres is already talked of as potentially supporting life, and it is relatively warm and wet. Internal heat prevents it freezing up – a future home?

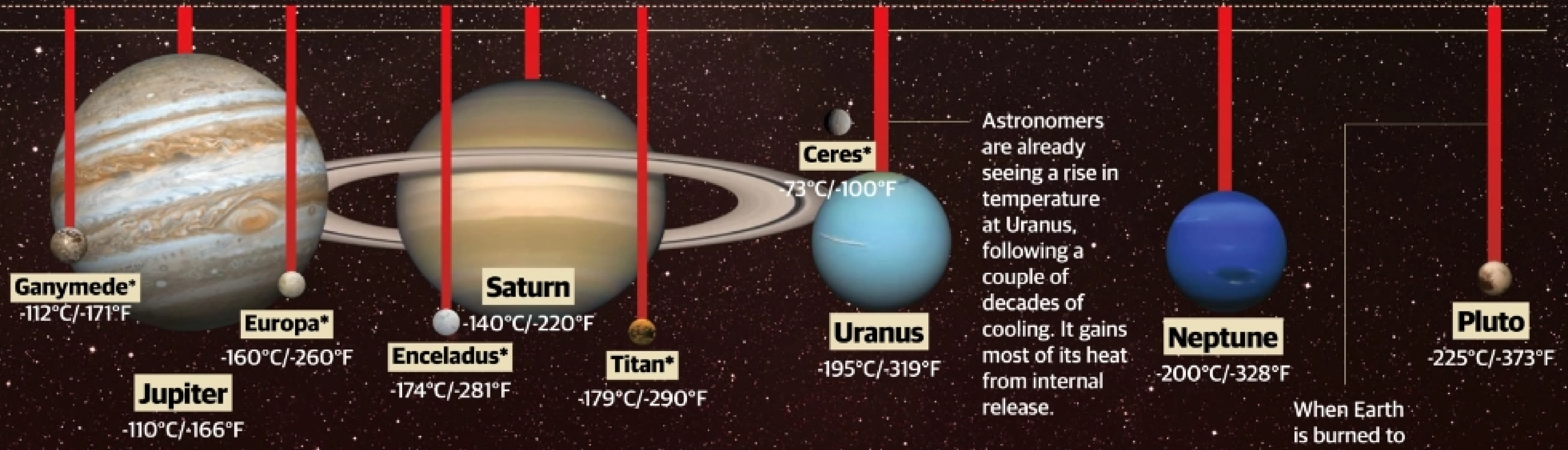
The impact of human industry

We've added carbon dioxide to the atmosphere, trapping more heat from the Sun. Our planet will adjust over time, but not soon enough to avoid severely impacting our way of life.

It's odd, but Neptune, despite being further away than Uranus, is actually warmer. It's atmosphere will boil off into space as it gets hotter.

END TEMPERATURE – WHERE THINGS TURN EXTREME

15C/59F



Astronomers are already seeing a rise in temperature at Uranus, following a couple of decades of cooling. It gains most of its heat from internal release.

When Earth is burned to a crisp, Pluto will end up being in an odd situation of having average temperatures that mirror our own today. It will have a liquid-water surface and a thick atmosphere.

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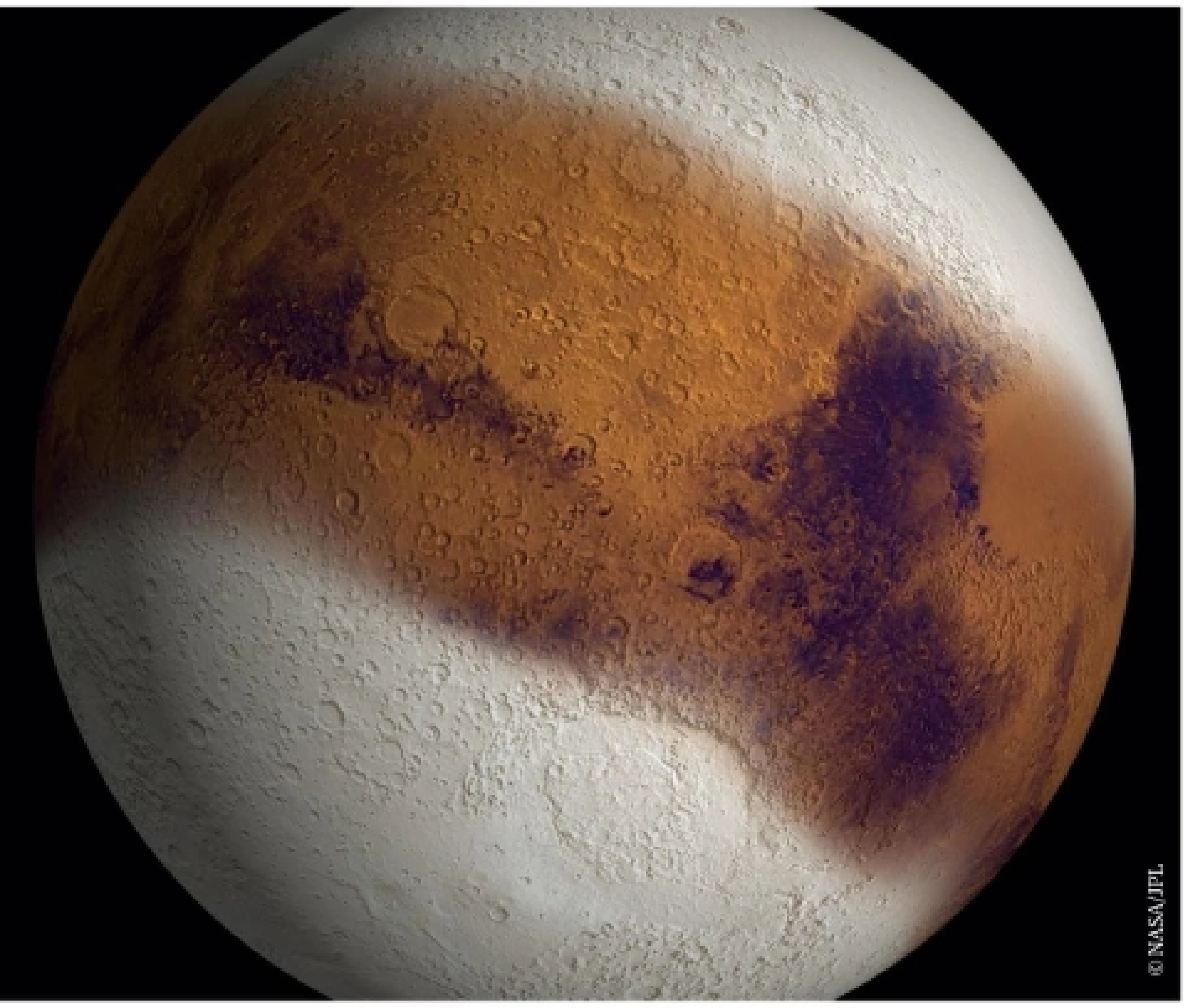


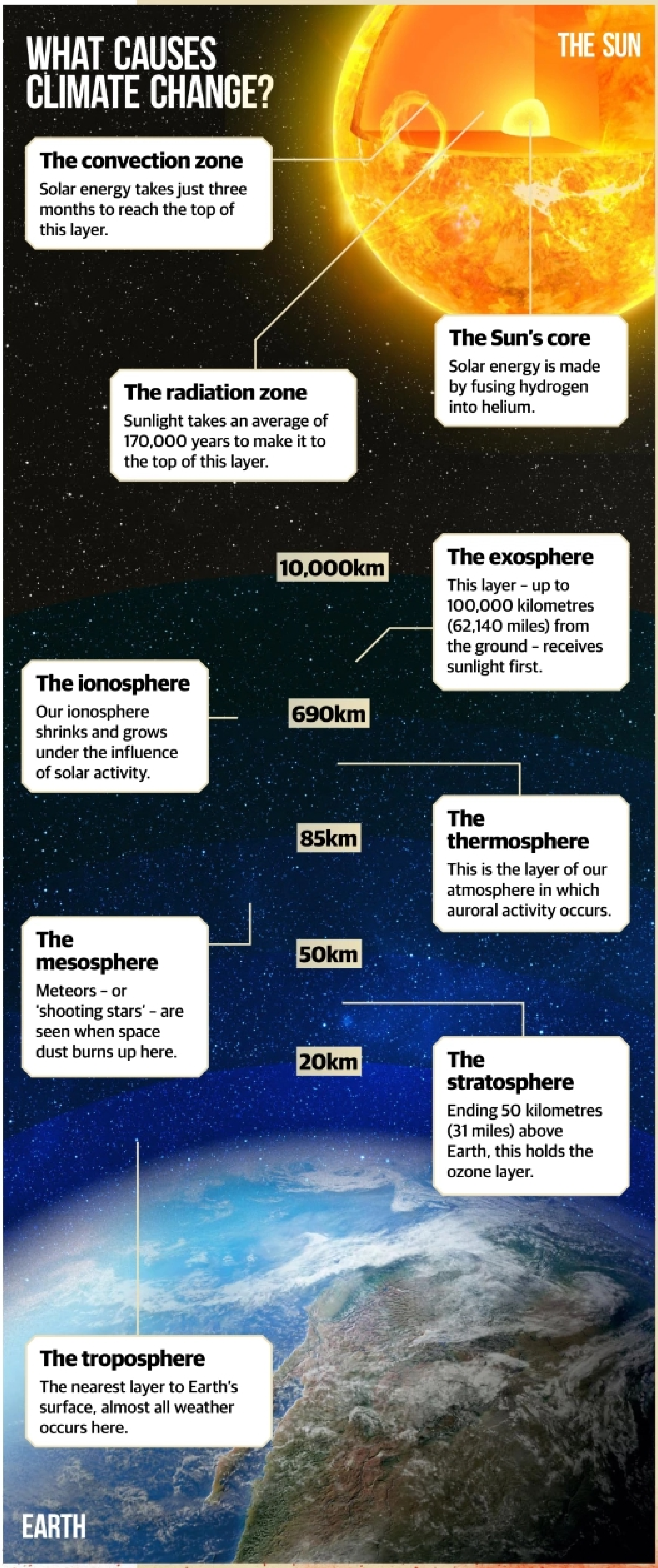
© NASA/JPL

Above: Like Earth, Mars has been through a series of ice ages throughout its history

and the Huygens lander that touched down on the satellite in 2005. "What it found shocked a lot of us - it blew people's minds," says Way. Like Earth there is liquid on the surface, which evaporates and condenses as rain. Yet instead of water it is methane, possibly because of the moon's very cold temperature. Researchers have also spotted complex chemicals known to be the building blocks of life. Understanding Titan's climate today could tell us whether it has ever had suitable conditions in the past for this chemistry to jump from prebiotic chains of molecules to full-blown biological organisms. Dragonfly could be a potential game changer in this effort. In the summer of 2019, NASA announced that it had approved the audacious rotorcraft lander that would take off and land in several sites across the Saturnian satellite, much like its insect namesake. It is due for launch in 2026 and will arrive in 2034. According to Way, climate modellers are "eagerly awaiting its arrival".

All these efforts to understand the climates of the worlds we share the Solar System with will do more than just inform our own battle against climate change. They will also give us a better idea of what exactly makes a planet habitable in the long term. That is sorely needed in the search for life beyond the Solar System. If Venus was a pleasant planet before volcanism ran rampant, then perhaps we shouldn't rule out planets in similar positions to Venus around other stars. Maybe there is too much focus on the idea of a habitable zone - the narrow region around a star where the temperature is right for liquid water. The contents of a planet's atmosphere has a huge role to play in distributing heat, and surely needs to be taken into account when assessing a world's suitability for life. Who knows, one day we may have to evacuate this planet. If so, knowing which worlds around the Sun and beyond could be new potential homes could prove vital to the continuation of our species.

WHAT CAUSES CLIMATE CHANGE?



The convection zone
Solar energy takes just three months to reach the top of this layer.

The Sun's core
Solar energy is made by fusing hydrogen into helium.

The radiation zone
Sunlight takes an average of 170,000 years to make it to the top of this layer.

The exosphere
This layer – up to 100,000 kilometres (62,140 miles) from the ground – receives sunlight first.

The ionosphere
Our ionosphere shrinks and grows under the influence of solar activity.

The thermosphere
This is the layer of our atmosphere in which auroral activity occurs.

The mesosphere
Meteors – or 'shooting stars' – are seen when space dust burns up here.

The stratosphere
Ending 50 kilometres (31 miles) above Earth, this holds the ozone layer.

The troposphere
The nearest layer to Earth's surface, almost all weather occurs here.

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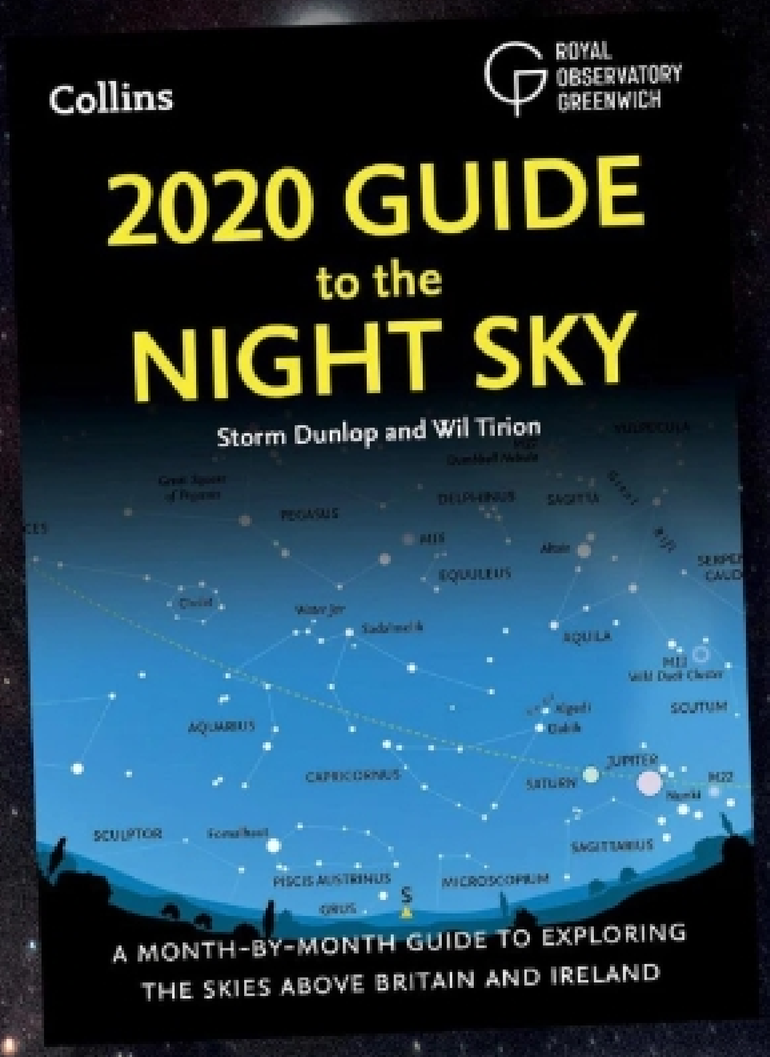
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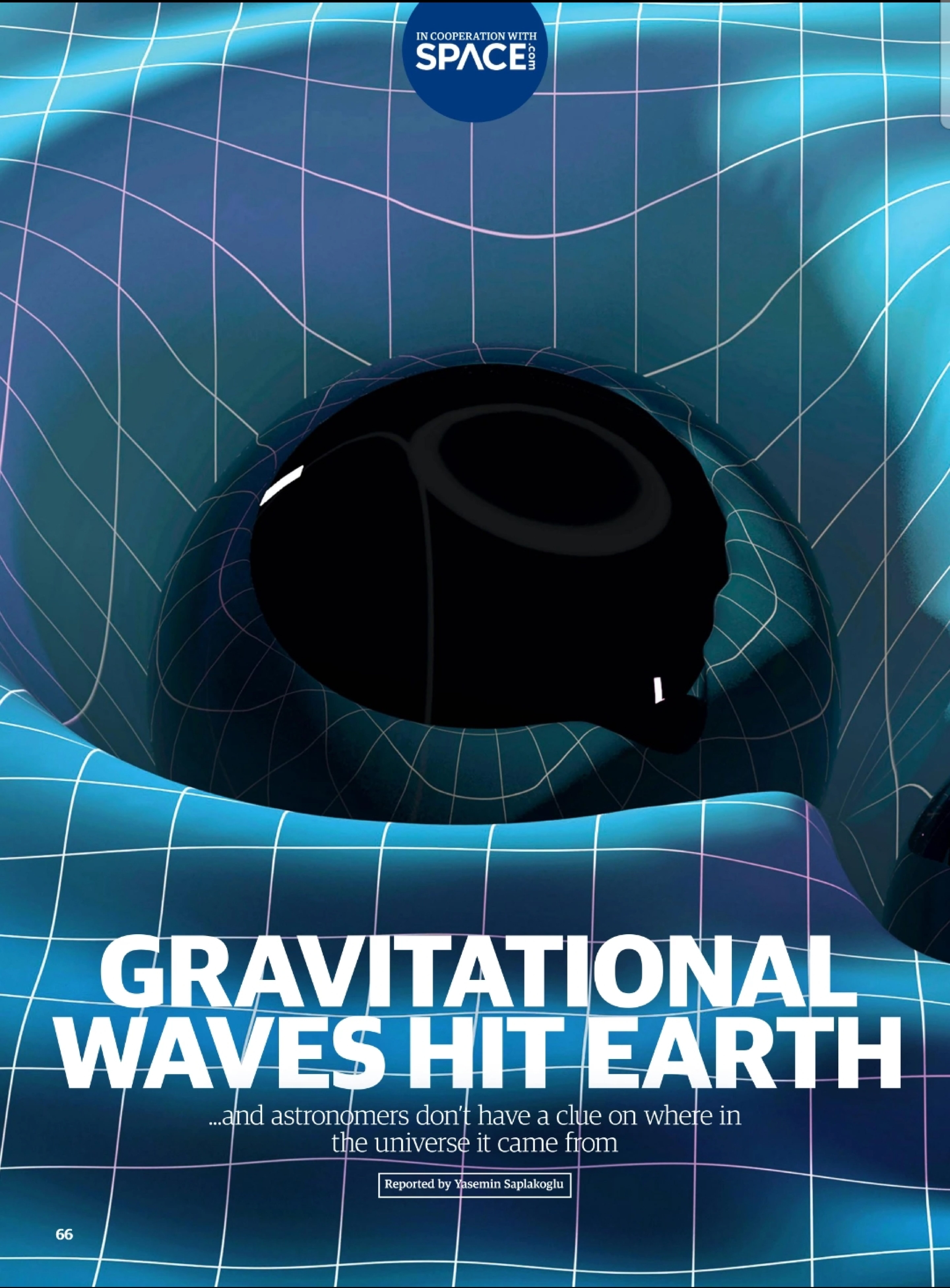
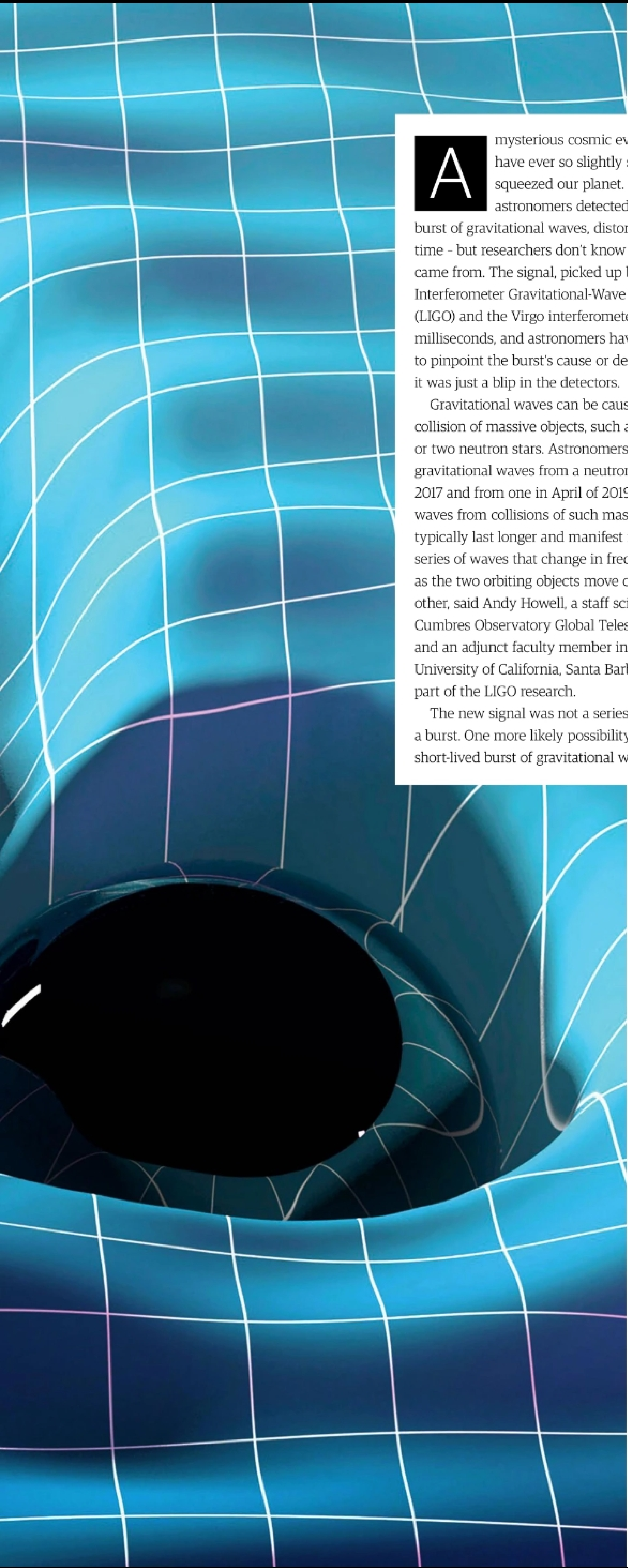


IN COOPERATION WITH SPACE.com

GRAVITATIONAL WAVES HIT EARTH

...and astronomers don't have a clue on where in the universe it came from

Reported by Yasemin Saplakoglu



A mysterious cosmic event might have ever so slightly stretched and squeezed our planet. On 14 January astronomers detected a split-second burst of gravitational waves, distortions in space-time – but researchers don't know where this burst came from. The signal, picked up by the Laser Interferometer Gravitational-Wave Observatory (LIGO) and the Virgo interferometer, lasted only 14 milliseconds, and astronomers haven't yet been able to pinpoint the burst's cause or determine whether it was just a blip in the detectors.

Gravitational waves can be caused by the collision of massive objects, such as two black holes or two neutron stars. Astronomers detected such gravitational waves from a neutron star collision in 2017 and from one in April of 2019. But gravitational waves from collisions of such massive objects typically last longer and manifest in the data as a series of waves that change in frequency over time as the two orbiting objects move closer to each other, said Andy Howell, a staff scientist at Los Cumbres Observatory Global Telescope Network and an adjunct faculty member in physics at the University of California, Santa Barbara, who was not part of the LIGO research.

The new signal was not a series of waves but a burst. One more likely possibility is that this short-lived burst of gravitational waves comes from a more transient event, such as a supernova explosion, the catastrophic ending to a star's life.

Indeed, some astronomers have hypothesised that this could have been a signal from Betelgeuse, which mysteriously dimmed recently and is expected to undergo a supernova explosion. But Betelgeuse is still there, so it's not that scenario. It's also unlikely to be another supernova because they happen in our galaxy only about once every 100 years, Howell added.

What's more, the burst still "seems a little too short for what we expect from the collapse of a massive star," he said. "On the other hand, we've never seen a star blowing up in gravitational waves before, so we don't really know what it would look like." In addition, the astronomers didn't detect any neutrinos, tiny subatomic particles that carry no charge, which supernovae are known to release.

Another possibility is that the merging of two intermediate-mass black holes caused the signal, Howell said. Merging neutron stars produce waves that last longer – around 30 seconds – than this new signal, while merging black holes might more closely resemble bursts that last for a couple of seconds. However, intermediate black hole mergers might also release a series of waves that change in frequency.

LIGO came across this signal while specifically looking for such bursts. But "that doesn't mean that what it found is an intermediate-mass black hole merger," Howell explained. "We don't know what they found," especially since LIGO hasn't yet released the exact structure of the signal, he added.

"Waves from collisions of such massive objects typically last longer"

It's also possible this signal was just noise in the data from the detector, Howell said. But this burst of gravitational waves was found by all three LIGO detectors: one in Washington state, one in Louisiana and one in Italy. The probability of the LIGO detectors finding this signal by chance is once every 25.84 years, which "gives us some indication that this is a pretty good signal," Howell said.

There could be other explanations for this mysterious burst, too. For example, a supernova could have directly collapsed into a black hole without producing neutrinos, though such an occurrence is very speculative.

Astronomers are now pointing their telescopes to that region to try to pinpoint the source of the waves. "The universe always surprises us," Howell added. "There could be totally new astronomical events out there that produce gravitational waves that we haven't really thought about."

Left: Ripples in space-time travel out from the collision of massive objects

© Mark Garlick/Science Photo Library

11 MISSIONS THE WORLD DOESN'T KNOW ABOUT

Away from the biggest names, there are some exciting plans in the pipeline from companies and agencies around the world

Reported by Lee Cavendish

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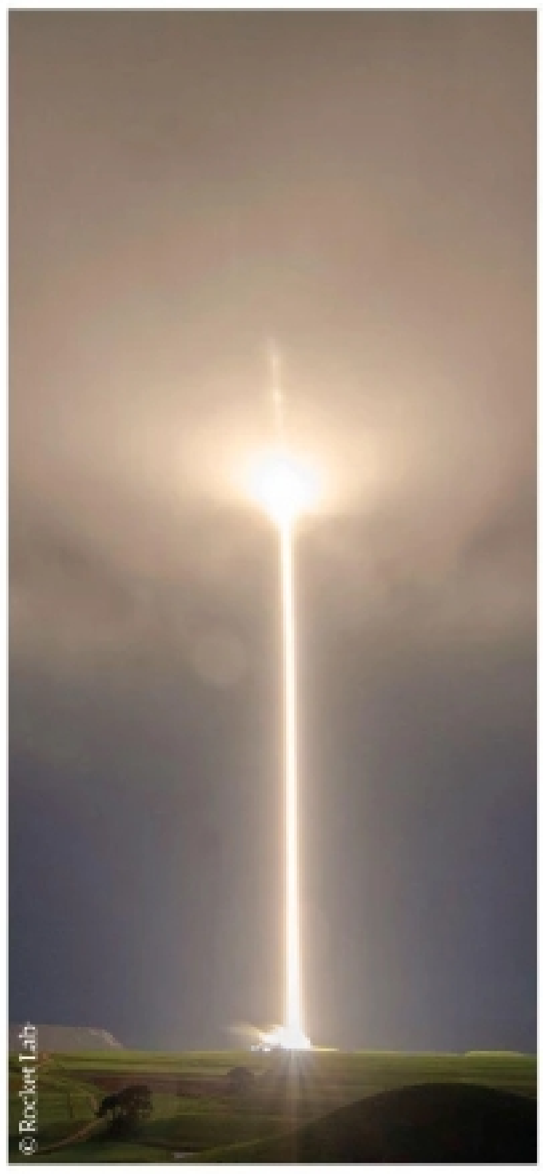
What are the first names that spring to mind when you think of space exploration? NASA? SpaceX? The European Space Agency? That's completely reasonable, seeing as they are making tremendous strides forward in this field. However, space is not restricted, and there are companies and agencies from a variety of countries that have their own plans, ideas and visions for the future.

In 2018 the global space economy was estimated to be worth £319 billion ($414.75 billion), and that figure is only going to grow. With companies offering easier and more affordable rides into space, the number of satellites in low-Earth orbit is growing by the week, and countries and enterprises are also realising that it's an industry that simply can't be ignored. No one can be expected to know all the goings-on from around the world, so here we present a selection of 11 lesser known, but equally exciting projects that are looking to make a real impact in the new decade.



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1 PERIGEE AEROSPACE WILL TEST ITS BLUE WHALE 1

A relatively unknown aerospace company from Daejeon, South Korea, is looking to unleash its own small launcher, with a maiden spaceflight scheduled for July 2020. This start-up has been developing a two-stage rocket called Blue Whale 1, and when operational it will be capable of transporting a 50-kilogram (110-pound) payload to a Sun-synchronous orbit.

Perigee Aerospace has claimed that Blue Whale 1 will be the smallest launcher in the world, standing at just 8.5-metres (28-feet) tall. The Atlas V two-stage rocket, which is renowned for its launches in the US, towers over it at 58 metres (190 feet). This tiny package packs a real punch though, and it can carry small payloads into low-altitude, high-inclination orbits, which is ideal for weather, remote-sensing and imaging satellites.

2 THE 'INTERNET OF THINGS' CONSTELLATION

US-based company SpaceX has begun launching its Starlink constellation, which consists of a number of satellites that will eventually provide worldwide internet access. Obviously it helps if you have your own rockets to launch them, and even more so if you have a billionaire entrepreneur backing you.

There are many other companies who are looking to pull off a similar endeavour, and one of these, Sky and Space Global, is currently waiting for the funds to complete its 'Internet of Things' constellation.

Sky and Space Global, an Australian company with branches in the UK, Poland and Israel, plans to place 200 CubeSats into low-Earth orbit to provide low-data-rate communications. The short-term goal is to raise £8.3 million ($10.8 million) in order to get an initial eight satellites into orbit. If the finances become available, Sky and Space Global will be able to launch its satellites, nicknamed 'Pearls', by the end of 2020. These satellites will provide high-quality voice and data communications and will be equipped with autonomous collision-avoidance software.

Below: Financial instability has moved the Pearl launches to the end of 2020

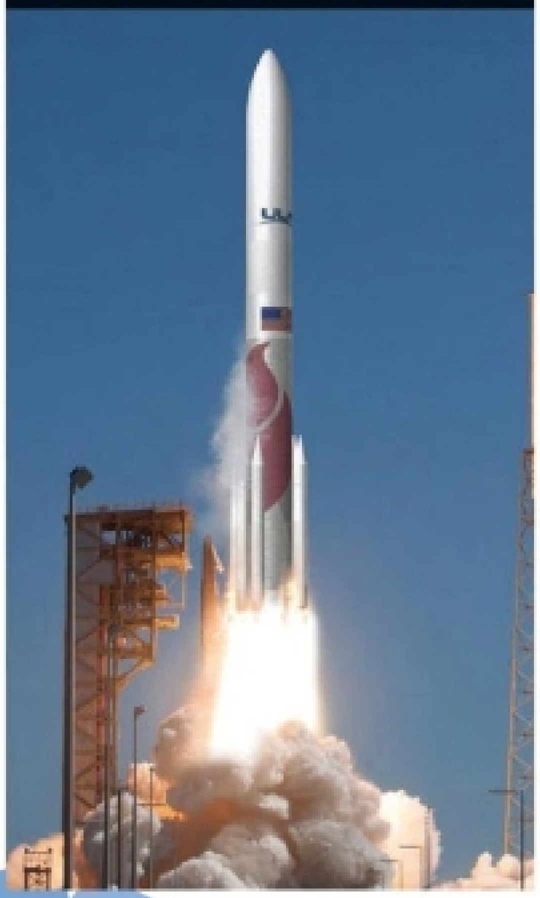
Sky and Space Global currently has three prototypes in orbit around Earth, which it refers to as the 'Three Diamonds'.

© GOMspace

3 NEXT-GEN HEAVY-LIFT LAUNCHER: VULCAN CENTAUR

Move over Delta IV and Atlas V: there's going to be a new player in town. United Launch Alliance, which operates the two aforementioned launchers, is now creating a two-stage heavy-lift rocket that will improve the capabilities of the US and its national security launch needs. United Launch Alliance aims to take the rocket designs from its hugely successful Delta IV and Atlas V rockets and incorporate new technologies that will provide more reliable and affordable launches.

One of the new additions to the Vulcan Centaur is the use of two Blue Origin engines in the first stage. The BE-4 engines, surrounded by up to six booster rockets, will provide the next generation of space launches. There is also talk of an additional Advanced Cryogenic Evolved Stage (ACES), which will allow operation in space for weeks instead of hours.



Left: United Launch Alliance has launched missions such as NASA's Curiosity rover, New Horizons and OSIRIS-REx

© United Launch Alliance

Collectively the two stages will use ten engines that will burn light hydrocarbons and liquid oxygen.

Right: Commercial operations for Spectrum could commence as early as 2022

© Isar Aerospace

4 ISAR AEROSPACE'S SPECTRUM

German start-up Isar Aerospace is developing its own two-stage rocket that is designed to launch satellite constellations into orbit. Its Spectrum will have the power to take 1,000 kilograms (2,200 pounds) to low-Earth orbit, and it's being developed at tremendous speed. Although the company only formed recently in 2018, it believes Spectrum could have its first taste of space in 2021.

This efficiency is possible because of the backing of Airbus Ventures and other investors providing £13 million ($17 million) in funding. When it's assembled the Spectrum rocket will stand at 27-metres (89-feet) tall. It will have a system similar to SpaceX's Falcon 9 in terms of engine configuration. Spectrum will have nine first-stage Aquila SL engines, and the second cryogenic stage will have a single Aquila VAC (vacuum) engine. Daniel Metzler, Isar Aerospace's chief executive, has stated that they would like the first stage to be reusable, but at the moment the focus is on creating an expendable design which can hopefully provide 15 launches per year.

5 VIRGIN ORBIT SATELLITE LAUNCHER

Sir Richard Branson's Virgin Galactic is gaining a lot of momentum in the space tourism world, which isn't much of a surprise when you consider the public interest in the project. However, its sister company, Virgin Orbit, is also making great strides in becoming a satellite launcher. Instead of the usual two-stage vertical rocket, like Spectrum, H3 and others mentioned here, Virgin Orbit will launch horizontally, with a two-stage rocket, LauncherOne, strapped onto a modified Boeing 747-400 aircraft, Cosmic Girl.

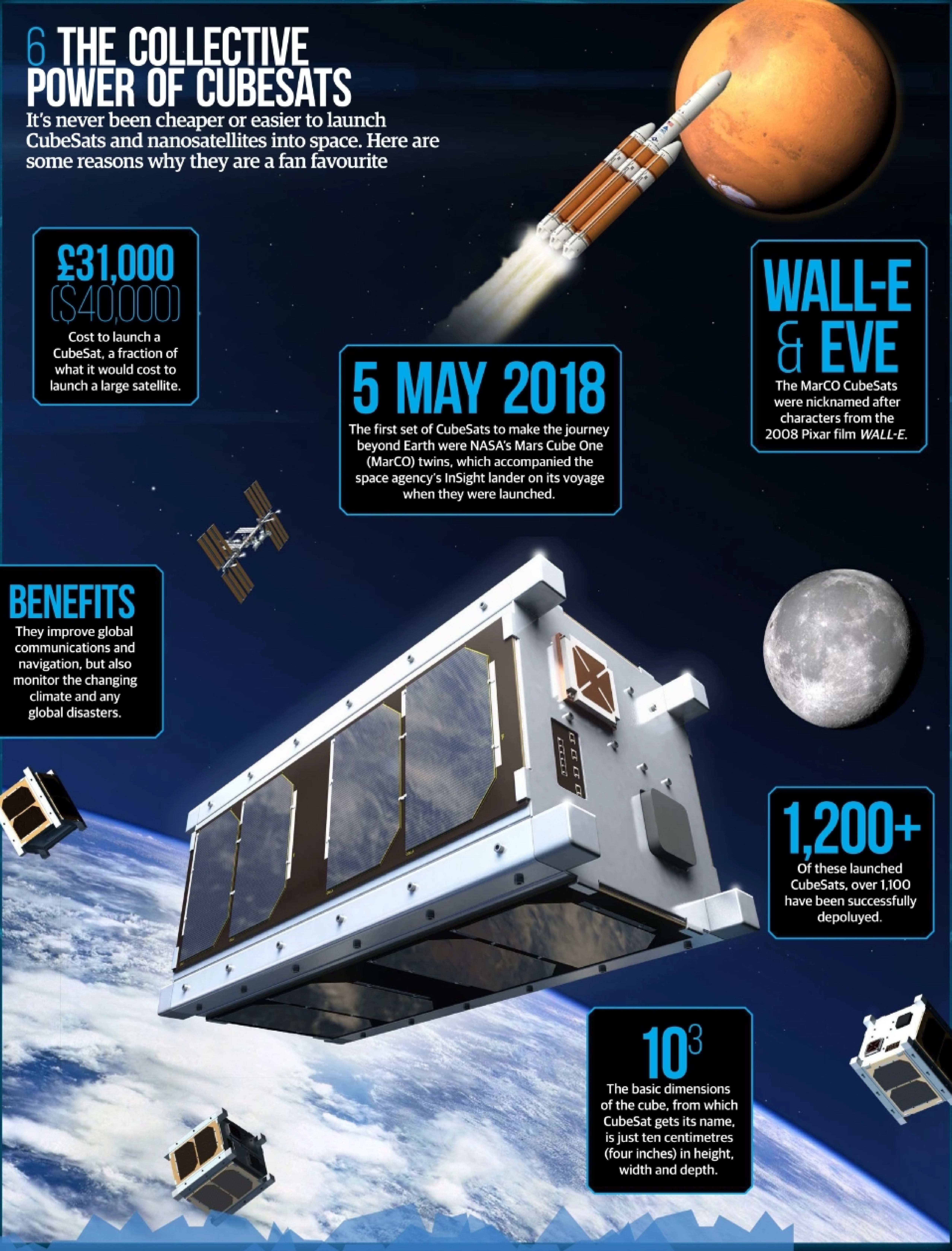
Upon launch, Cosmic Girl will ferry LauncherOne to an altitude of 11,000 metres (35,000 feet), where the rocket will be dropped, then carrying a payload of between 300 and 500 kilograms (660 and 1,100 pounds) into orbit. The Virgin Orbit team is also in the process of introducing a third stage to the rocket that will launch interplanetary missions. This third stage could take 50 kilograms (110 pounds) to Mars, 70 kilograms (150 pounds) to Venus or over 100 kilograms (220 kilograms) to the Moon. The first flight of Virgin Orbit's LauncherOne could occur in early 2020, but that is assuming that everything goes to plan and its construction stays on schedule.

Right: Virgin Orbit could deploy payloads into space from spaceports all over the globe

© Virgin Orbit

6 THE COLLECTIVE POWER OF CUBESATS

It's never been cheaper or easier to launch CubeSats and nanosatellites into space. Here are some reasons why they are a fan favourite



£31,000 ($40,000)

Cost to launch a CubeSat, a fraction of what it would cost to launch a large satellite.

5 MAY 2018

The first set of CubeSats to make the journey beyond Earth were NASA's Mars Cube One (MarCO) twins, which accompanied the space agency's InSight lander on its voyage when they were launched.

WALL-E & EVE

The MarCO CubeSats were nicknamed after characters from the 2008 Pixar film *WALL-E*.

BENEFITS

They improve global communications and navigation, but also monitor the changing climate and any global disasters.

1,200+

Of these launched CubeSats, over 1,100 have been successfully depoluyed.

10^3

The basic dimensions of the cube, from which CubeSat gets its name, is just ten centimetres (four inches) in height, width and depth.

© Adrian Mann

7 PROJECT KUIPER WORKS TOWARDS A GLOBAL INTERNET

Amazon plans to launch a satellite mega-constellation that will provide internet to tens of millions of people around the globe. This audacious project, nicknamed Project Kuiper, is aiming to put 3,236 satellites into three set of orbits at altitudes of 590, 610 and 630 kilometres (367, 379 and 391 miles).

The company's AWS Ground Station unit will have 12 facilities scattered over the world, which is vital for the ground-to-space communications. The mega-constellation will be able to gift its low-latency, high-speed broadband connectivity to people between the latitudes of 56 degrees north and 56 degrees south, restricted by the orbits of the thousands of satellites. There hasn't been a timeline stated for this project other than that it's long-term.

Left: Internet access has recently become a global necessity, as opposed to more of a privilege

© Getty

8 PORTUGAL'S SECURITY SATELLITES

Portugal's recently assembled space agency is thinking long and hard about what its initial plans and objectives should be. There have been in-depth discussions about whether it should construct its own spaceport, but because of its access to the Atlantic Ocean and closeness to the equator, it makes perfect sense. The space agency is also strongly considering launching a constellation of satellites so that it can keep a watchful eye on the maritime activity in the Atlantic Ocean.

This constellation would be less focused on providing citizens of the world with internet and is more about protecting the countries of the world that have a sea border. With this constellation, Portugal will have an advantage when it comes to clamping down on coastal crimes such as illegal fishing, maritime piracy and ocean pollution. There isn't any definitive plans for this fleet of space-based security satellites, but the agency has stated that it wants to be a real authority over the Atlantic region.

Right: Portugal is a large coastal country bordering Spain and the Atlantic Ocean

Portugal is looking to stamp itself into the space industry with its recently announced 'Portugal Space 2030'.

© NASA

9 A FLEET OF UNITED ARAB EMIRATES ASTRONAUTS

The United Arab Emirates (UAE) has shown increasing interest in the world of space exploration, with it creating its own space agency in 2014. The country has stated that it is open to the introduction of Virgin Galactic operations, and is also planning its own missions to space. Recently the UAE saw its first astronaut emerge when Hazza Al Mansouri visited the International Space Station (ISS) in September 2019.

Now the country is planning to assemble its own astronaut corps, training a selected number of people from a staggering number of applicants. The Emirati space agency announced its plans for an astronaut corps in 2017 and recently announced that there have been more than 4,000 applicants. The ages of the applicants range from 17 to 67, and over a third of them were women. This shows promising signs for the country as it looks to build a sustainable programme that has a constant string of Emiratis in space, contributing to scientific research and future missions.

Right: Hazza Al Mansouri became the first Emirati astronaut in September 2019 as part of the Soyuz MS-15/12 mission

© NASA

10 JAXA AND MITSUBISHI'S H3 ROCKET

The Japan Aerospace Exploration Agency (JAXA) is teaming up with one of the country's major engineering companies, Mitsubishi Heavy Industries (MHI), part of the wider Mitsubishi Group, which has brought the world its famous array of cars. However, in this case the Japanese industrial team is looking to create a more powerful transport vehicle that can take packages a bit further, and a bit more vertical.

JAXA and MHI are currently in the process of constructing an expendable, two-stage rocket that will shepherd cargo to the International Space Station (ISS) - which it will hopefully do in 2021. But with the increasing momentum of NASA's Artemis mission - the mission that will return men and bring the first woman to the surface of the Moon - Japan now wants to ramp up the capabilities of the H3 rocket in order to shepherd cargo to the Moon as well.

While Artemis aims to put this new generation of astronauts on the lunar surface by 2024, JAXA and MHI are hoping that lunar deliveries will commence in 2025 or 2026, which will either put lunar landers straight into orbit around our celestial neighbour or will deliver important supplies to a space station in orbit around the Moon, to be called the 'Lunar Gateway'.

The H3 rocket could launch 11,900 kilograms (26,200 pounds) to the proposed Lunar Gateway or 28,300 kilograms (62,400 pounds) to low-Earth orbit.

Japanese engineers are aiming to make H3 'the world's quietest launch' by utilising sound-absorbing walls and paying close attention to noise in testing.

MHI is developing a set of inspection protocols that could narrow the idle period between rocket launches to just 30 days.

Right: The H3 rocket will deliver cargo to the ISS or beyond to the Moon

"THE BE-4 ENGINES, SURROUNDED BY UP TO SIX BOOSTER ROCKETS, WILL PROVIDE THE NEXT GENERATION OF SPACE LAUNCHES"

© JAXA

11 THE UAE'S HOPE MARS MISSION

There's a truly historic mission commencing in 2020 that is going under the radar: the Hope Mars Mission, also known as the Emirates Mars Mission. This UAE-funded mission is the first interplanetary mission by the UAE and by any Islamic country. When Hope Mars arrives at the Red Planet in 2021, it will also coincide with the 50th anniversary of the formation of the UAE.

In terms of science and engineering, this mission, a Mars orbiter, is being built at the Emirati's Mohammed bin Rashid Space Centre, in collaboration with the University of Colorado, University of California, Berkeley, and Arizona State University, all in the US. The spacecraft will have three state-of-the-art instruments that will provide unprecedented information about the planet's weather and atmospheric history. This will hopefully provide some answers in regards to what Mars' atmosphere was like billions of years ago, what is driving out the hydrogen and oxygen from the atmosphere and how the atmosphere varies over the course of a year, season or even a day.

© Mohammed bin Rashid Space Centre

Right: The UAE announced its Mars mission back in July 2014

ASK Space

Our experts answer your questions

SOLAR SYSTEM

How does organic material on Enceladus compare to that found on Mars?

The most intriguing difference is how easily one finds complex organics on Saturn's moon Enceladus compared to Mars. If you consider the enormous efforts put into the search for organics on Mars since the 1970s without success, it is just amazing how easily we found complex and diverse organic chemistry on Enceladus just with a spacecraft flying by. However, it is a huge success that NASA's Curiosity finally found organics on Mars. From what I read the organics on Mars – like the Enceladean ones – could be large molecules that contain aromatic and aliphatic structures. Whereas we find oxygen and probably nitrogen in both organic molecules, the Mars organics do contain sulphur. The Cassini instruments were not very sensitive to sulphur, so it might be the case that it is there as well without us noticing it.

On Mars about 50 space missions with several generations of rover were required. On Enceladus it was just one exploratory spacecraft with instruments on board that were not even built to investigate Enceladus in the first place. Keep in mind that Cassini and its instruments were built before scientists even knew about the activity on Enceladus. Just imagine what a much better job in looking for life we could do if we just spend a small fraction of the time and money that was spent for Mars to go back to Enceladus with instruments that are actually built to do that.

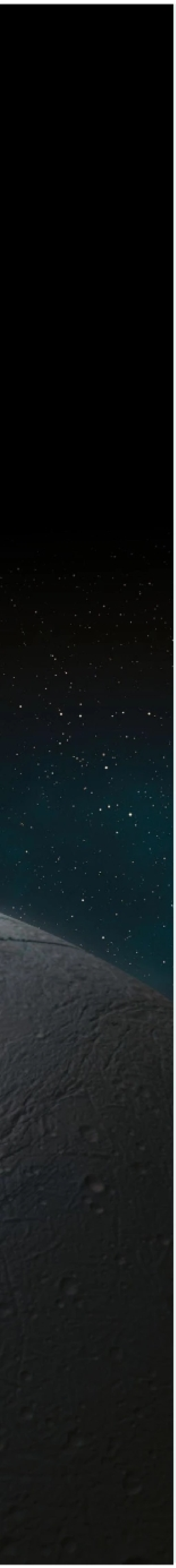
Frank Postberg is a planetary sciences professor in the Department of Earth Sciences at FU Berlin

Below: Rare organic chemistry was detected erupting from Saturn's moon Enceladus by NASA's Cassini spacecraft

© Tobias Roetsch

Did you know?

Enceladus is the sixth-largest Saturnian moon, with a diameter of 505 kilometres (314 miles).



Right: 2I/Borisov is the first observed interstellar comet and was discovered in August 2019

Below: CHEOPS will be the next space exploration mission launched by the European Space Agency

SOLAR SYSTEM

Why is the discovery of interstellar comet Borisov so important?

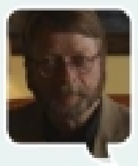
© NASA, ESA

Was 'Oumuamua a fluke visitor, a unique voyager from beyond our Solar System, or are there others? Since 'Oumuamua was identified as an interstellar traveller in late 2017, it was the first of its kind for astronomers on Earth. With the discovery of comet Borisov, the club may have just gotten a whole lot bigger.

Astronomers will have months to observe comet Borisov as it continues to move towards the Sun and then away. Scientists will get an accurate fix on its location and trajectory, letting them know with confidence whether it's really from outside our Solar System, as initial data suggests.

If we observe only one interstellar asteroid or comet, it's always possible it was a freak event, never to be repeated. But as soon as we detect a second, we know there'll soon be many more discoveries.

One of the most daunting obstacles to interstellar panspermia is having an asteroid or comet for life to tag along with. With the discovery of Borisov, that challenge seems much less daunting.



Douglas Vakoch is an astrobiologist and president of Messaging Extraterrestrial Intelligence (METI) International

> "If we observe only one, it's always possible it was a freak event"
>
> **Douglas Vakoch**

SPACE EXPLORATION

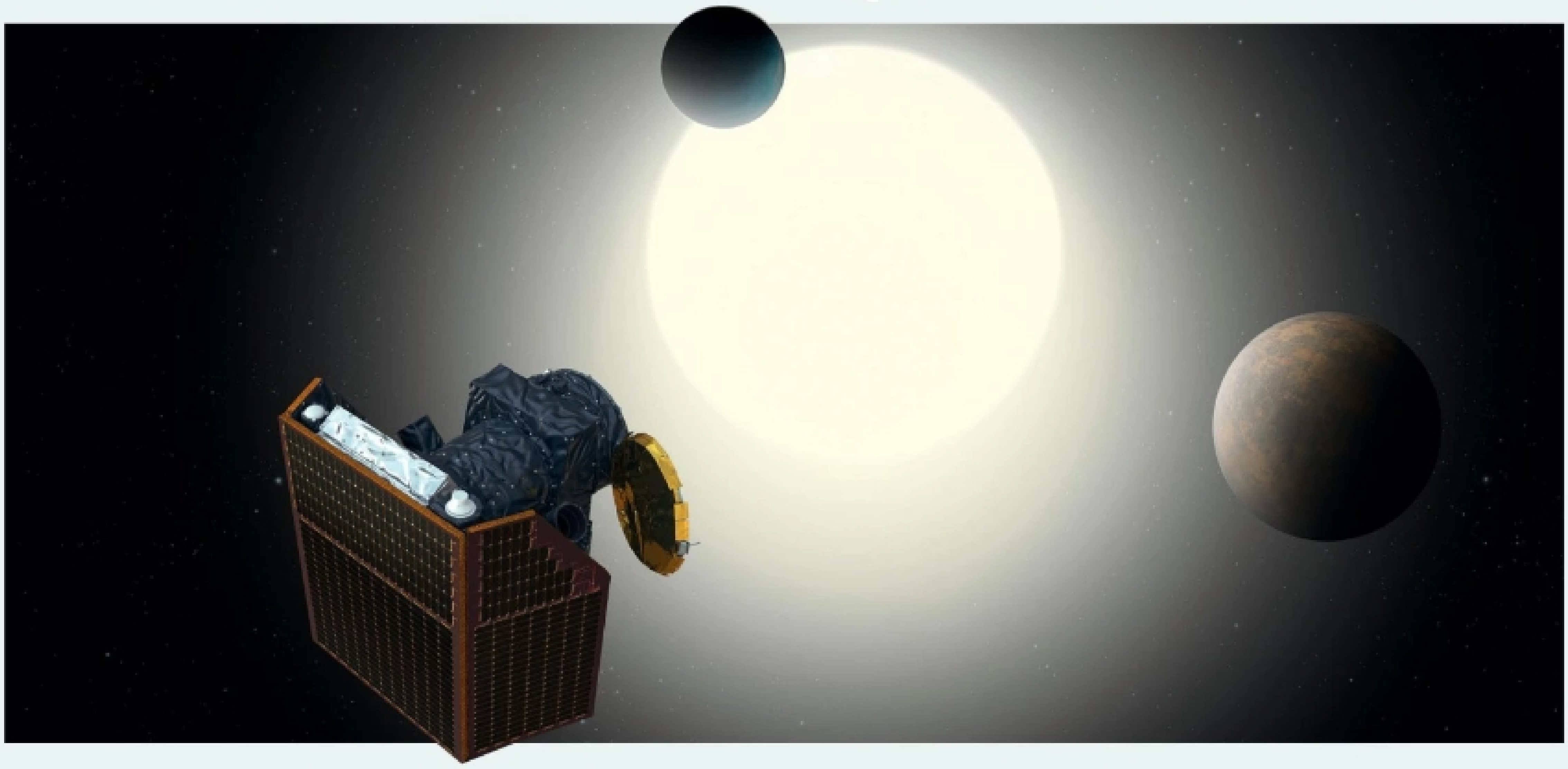
What will be the European Space Agency's (ESA) next exciting mission?

CHEOPS (CHaracterising ExOplanets Satellite) is all ready. It's all been tested, and it's gone through everything that it needs to go through. It's going to be launched with an Italian military satellite called COSMO-SkyMed on either a Vega or Soyuz [rocket], but it's riding as a passenger, so we had to wait until COSMO-SkyMed is ready, and then CHEOPS will go with it.

Early this year is our next launch, the Solar Orbiter, which is a collaborative mission with NASA, and that will be launched on a US launcher in February [2020]. It will be going very close to the Sun, inside the distance of Mercury, and then also a high latitude looking down on the Sun from above, which is unique. And then we've got the JWST, the James Webb Space Telescope. That's coming in 2021, but before that we're hopefully going to launch the ExoMars mission, with a rover, to Mars this summer – so it's a very busy year coming.

Of course, you know, not everything will launch on time, but that's the plan at the moment. Let's see how it works out over the next 12 months.

Professor Mark McCaughrean is senior science advisor in the Directorate of Science at the ESA



© ESA

ASTROPHYSICS

How does time act around black holes?

If I go close to a black hole, time slows down for me. In fact, it will slow down completely if I get to the event horizon – which is essentially the surface of a black hole. This means, for instance, if we put in enough money to build a spacecraft and go there, and then wait a few months in a close proximity of the black hole, and then I turn my engine on and I come out, when I come out, I am very much in the future with respect to when I went in.

I could stay there for ten minutes for me, and when I come out, maybe 3,000 years have passed. A black hole is a time-slower. It's something that when you go there and you jump to the future, time for you goes extremely slower, while outside it continues faster. We know that it is one of the physical effects that allowed us to compute what happens in the proximity of a black hole and predict the image of the black hole that was seen in 2019.

Carlo Rovelli is a theoretical physicist at the Centre de Physique Théorique de Luminy of Aix-Marseille University

© Nichols Forder

SOLAR SYSTEM

Does the greater threat to Earth come with climate change or from space?

Ultimately, we feel small when we watch films about the Solar System and beyond. I think there's a sense in which we feel detached from nature, and that would be a mistake. Science is an attempt to understand nature, of which we're a part, and that's vital for our survival. There is a legitimate question we could ask: how do planetary atmospheres evolve? What we've found is that planetary atmospheres are rather fragile things in a sense, and they can evolve in response to quite small changes, and we've seen that not only by measuring the Earth's atmosphere and modelling it, but also trying to model Venus' atmosphere. In particular where we also deploy our climate models, and also Mars' atmosphere and how it lost its atmosphere, which is also a target for our climate models. Investigating the Solar System allows us to test our understanding of the Earth. That's the point, because we have different laboratories, so that's number one.

But number two, the threat of an asteroid strike, for example, is very real. It does happen. Carl Sagan – this is one of my favourite quotes, I always quote it – he said, "If the dinosaurs had a space programme, they'd still be around." But he was making a serious point that we do live in a challenging environment, and the more we understand about it, and the more we develop our technologies, it may allow us to mitigate some of these threats. This makes it more likely we are able to survive. I think that's also important. That's not science fiction, it's a real issue.

Brian Cox OBE is a professor of particle physics in the School of Physics and Astronomy at the University of Manchester, UK

Left: An asteroid impact would pose a huge threat to the Earth

Right: Hot-Jupiters are very easy to spot, but that doesn't mean they are typical throughout the cosmos

© NASA, ESA

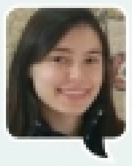
SOLAR SYSTEM

Why isn't Jupiter close to the Sun like the hot Jupiter exoplanets discovered around other stars?

Jupiter and Saturn formed in the outer Solar System, in a disc of gas and dust surrounding the young Sun. They built up massive cores, which subsequently attracted gas from the disc that formed their atmospheres. The leading theory for Solar System formation suggests that they experienced some migration inward and then outward, settling into their present locations.

Hot Jupiters are challenging to form at their current locations because the amount of solid material needed to build up their cores is more than is expected to be found at such a close-in orbital distance. This suggests that hot Jupiters may have formed on a further-out orbit and were transported inward. For example, the hot-Jupiter could have experienced a violent dynamical encounter with another gas giant further out which slingshotted the hot-Jupiter onto its present, very close-in orbit.

Another possibility is that the hot Jupiter migrated in much more gradually through the disc to its current location. Though systems hosting hot Jupiters are very different from our own, both are thought to have undergone planetary migration. Planetary systems have rich dynamical histories, the outcomes of which are seen in the diversity of exoplanetary systems.



Renata Frelikh is an astronomer at UC Santa Cruz, California

SPACE EXPLORATION

How does a real-time rocket launch compare to simulations in training?

Right: Haise was launched into space on top of a Saturn V rocket

© NASA

Our simulations did not include any of the dynamics of the ride on the booster but primarily trained us to recognise system problems with the boosters that might require an abort or takeover of control. At liftoff you could tell that you were moving, but it was not a 'big kick in the pants'.

The couches we laid in were suspended with some clearance provided on each side so they could stroke in the event of a hard landing from failed parachutes, or even to support an abort resulting in a landing on land. The highest g level was a bit over 4 g; that was modest compared to our past career experience with combat manoeuvring in fighter aircraft. The biggest surprise to me was when the engines shut down ahead of staging. If I hadn't been strapped in, I would have been thrown into the instrument panel.

Fred Haise flew on board Apollo 13

Did you know?

Apollo 13 was intended to land in the Fra Mauro Highlands on the Moon, but due to an oxygen tank explosion it had to return to Earth.

SPACEX'S STARLINK CATCH ASTRONOMERS OFF GUARD

The satellites launched so far are much more visible than expected

© Getty

SpaceX founder and CEO Elon Musk announced the Starlink concept back in January 2015, explaining the company intended to launch about 4,000 broadband satellites into low-Earth orbit to provide low-cost internet to people around the world.

The envisioned numbers have grown since then. SpaceX now has permission from the US Federal Communications Commission to loft about 12,000 Starlink craft, and the company has applied to an international radio-frequency regulator for approval of up to 30,000 additional satellites. For perspective, there are only about 2,000 operational satellites in orbit today, and humanity has launched only around 9,000 craft into space in all of history.

Shortly after deployment, the Starlink craft look like a bright string of pearls as they race together across the sky. This formation disbands as the 225-kilogram (500-pound) satellites disperse and climb to their final operational altitude about 550 kilometres (342 miles) above Earth's surface – but the individual spacecraft remain visible to the naked eye, even way up there.

© Farra Observatory

"What surprised everyone was how bright their satellites are," said Patrick Seitzer of the University of Michigan. "We knew these megaconstellations were coming, but based on the sizes and shapes of things currently in orbit, I thought maybe eighth or ninth magnitude," Seitzer added. "We were not expecting second or third magnitude in the parking orbits, and we were certainly not expecting fourth to fifth magnitudes in the [operational] orbits." This surprising brightness has many astronomers worried. The huge number of coming Starlink satellites could severely compromise the ability of ground-based telescopes to do their work.

The high-profile project most likely to be affected is the Vera Rubin Observatory, scheduled to come online a few years from now in the Chilean Andes. "The survey is the most impacted by bright satellite trails because of its wide field of view and extreme sensitivity," Seitzer said.

But Starlink's effects will be felt beyond the astronomical research community – indeed, by pretty much everyone around the world. The star-filled night sky is an international resource, and one of the only ways that many people commune with nature in our increasingly urban and technological world, said Ruskin Hartley, executive director of the International Dark Sky Association. "The night sky is the ultimate public good; it's our ultimate commons," Hartley said during a news conference. "No one individual can protect it. And the flip side, I believe, [is] no one individual should be allowed to despoil that."

Astronomers have voiced their concerns to SpaceX and found a receptive audience, said Jeffrey Hall, the director of Lowell Observatory in Flagstaff, Arizona. "We have not had to cajole SpaceX in any way; they've been very receptive, very proactive, in holding roughly monthly telecons with us," said Hall. "It's been a little more staying in touch than making a lot of progress on mitigation." One of the 60 spacecraft that launched in January sported a special coating designed to reduce its brightness. If everything goes well, and the coating doesn't seriously affect the satellite's performance, this mitigation measure could eventually become widespread.

Not everyone is satisfied by such steps. Astrophysicist and science communicator Ethan Siegel asked: "Why should astronomers trust SpaceX – which knows about this problem but is deliberately worsening this instead of addressing it before additional launches – instead of seeking a legal or international mandate for regulation?" In response, Hall explained that the astronomy community doesn't really have much choice. "The launches are underway right now. I think regulation of the Wild West up there is necessary; that is going to take a great deal of time to implement, just because of the nature of that beast," Hall said. "Therefore, there is no advantage or upside to distrusting what SpaceX colleagues have told us," he added. "We will simply take them at face value and work as best as we can and honestly with them to try to solve the situation."

WHAT PROBLEMS COULD STARLINK CAUSE?

- Could hide Earthbound killer asteroids
- Force scientists to rewrite software to auto-detect meteors
- Interfere with the operation of telescopes and observatories
- Create an impenetrable wall of space junk

© SpaceX; Getty

STARGAZER

ESSENTIAL GUIDES AND ADVICE FOR AMATEUR ASTRONOMERS

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Make the most of the early spring sights and longer nights before the clocks go forward

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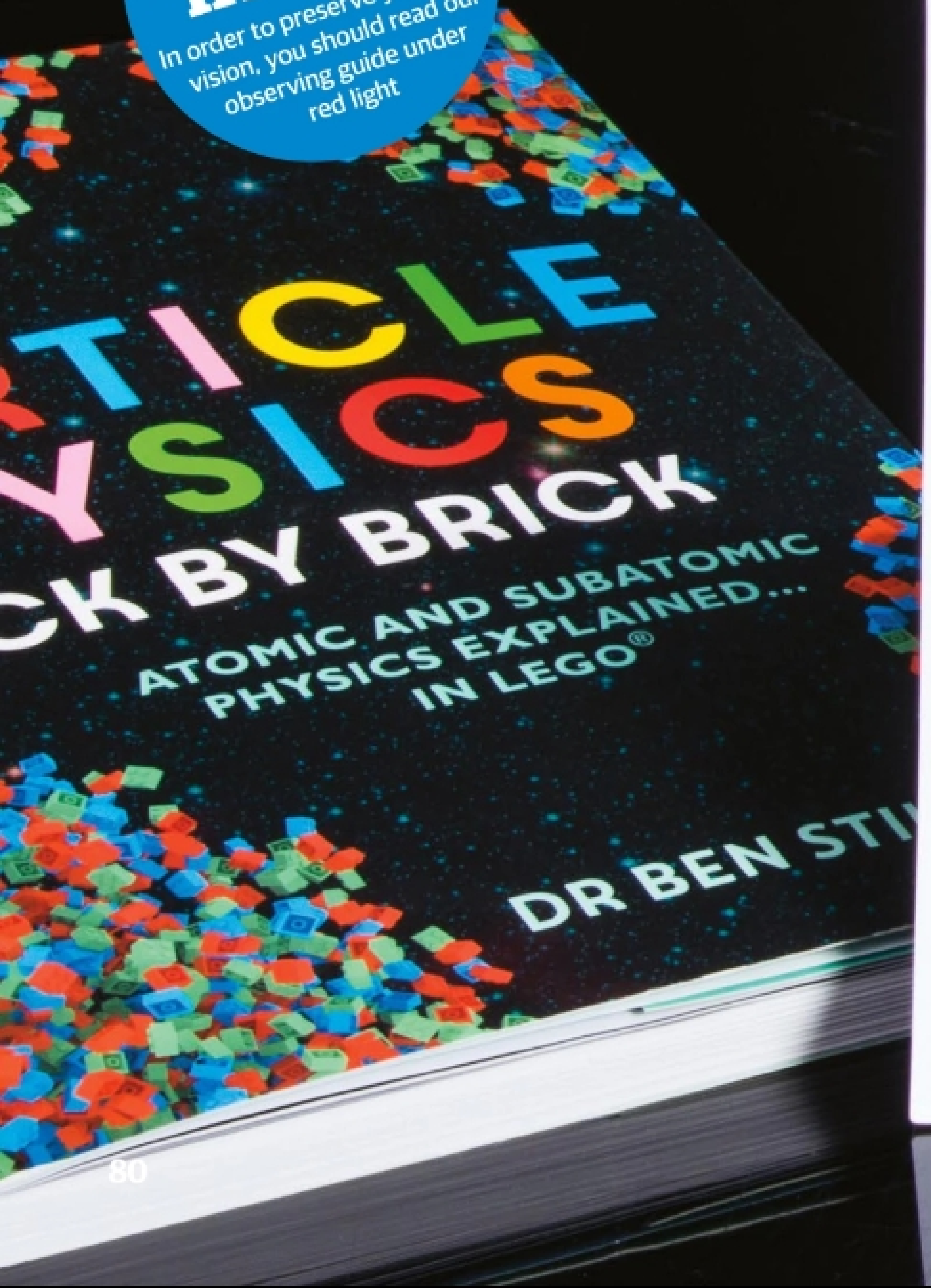
What's in the sky?

Red light friendly

In order to preserve your night vision, you should read our observing guide under red light

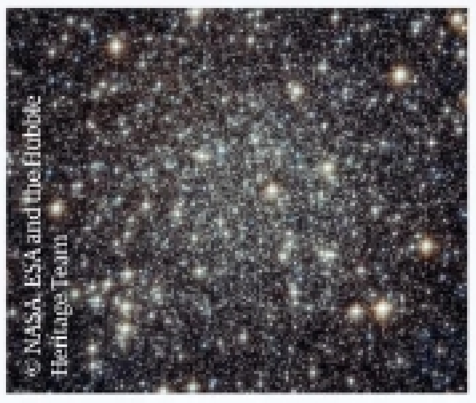


27 FEB

Conjunction between the Moon and Venus in Pisces

28 FEB

Messier 22 and Mars make a close approach, passing within 0°20' of each other in Sagittarius


© NASA, ESA and the Hubble Heritage Team

15 MAR

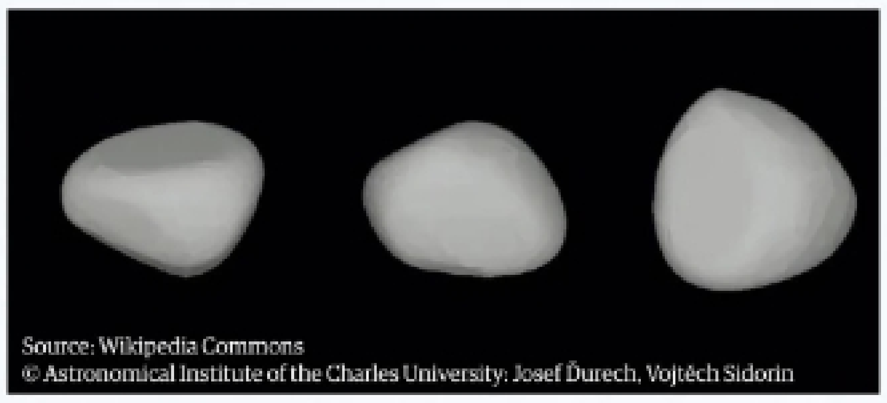
Asteroid 27 Euterpe reaches opposition in Virgo, glowing at magnitude +9.4

18 MAR

Mercury reaches its highest point in the evening sky, shining at magnitude -0.6

18 MAR

The Moon and Mars make a close approach, passing within 0°44 of each other in Sagittarius


Source: Wikipedia Commons
© Astronomical Institute of the Charles University: Josef Ďurech, Vojtěch Sidorin

19 MAR

The Moon and Saturn make a close approach, passing in Capricornus and Sagittarius

22 MAR

Mercury will reach half phase (dichotomy) in the morning sky, shining brightly at +0.2

23 MAR

Conjunction between Mars and Pluto in Sagittarius

23 MAR

Mars and Pluto make a close approach, passing within 0°01' of each other in Sagittarius

Jargon buster

Conjunction

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

6 MAR ∞
The Moon and Mars make a close approach, passing within 1°23' of each other in Cancer

9 MAR 🔭
Conjunction between Venus and Uranus in Aries

13 MAR 👁
Mercury reaches its highest point in the morning sky, shining brightly at +0.2

18 MAR 👁
Conjunction of the Moon and Jupiter, passing within 1°30' of each other in Sagittarius

18 MAR 👁
The Moon, Mars and Jupiter make a close approach in Sagittarius

18 MAR 👁
Conjunction between the Moon and Saturn in Sagittarius

20 MAR ☀
March Equinox

20 MAR 👁
Conjunction between Jupiter and Mars in Sagittarius

20 MAR 👁
Jupiter and Mars make a close approach, passing within 0°42' of each other in Sagittarius

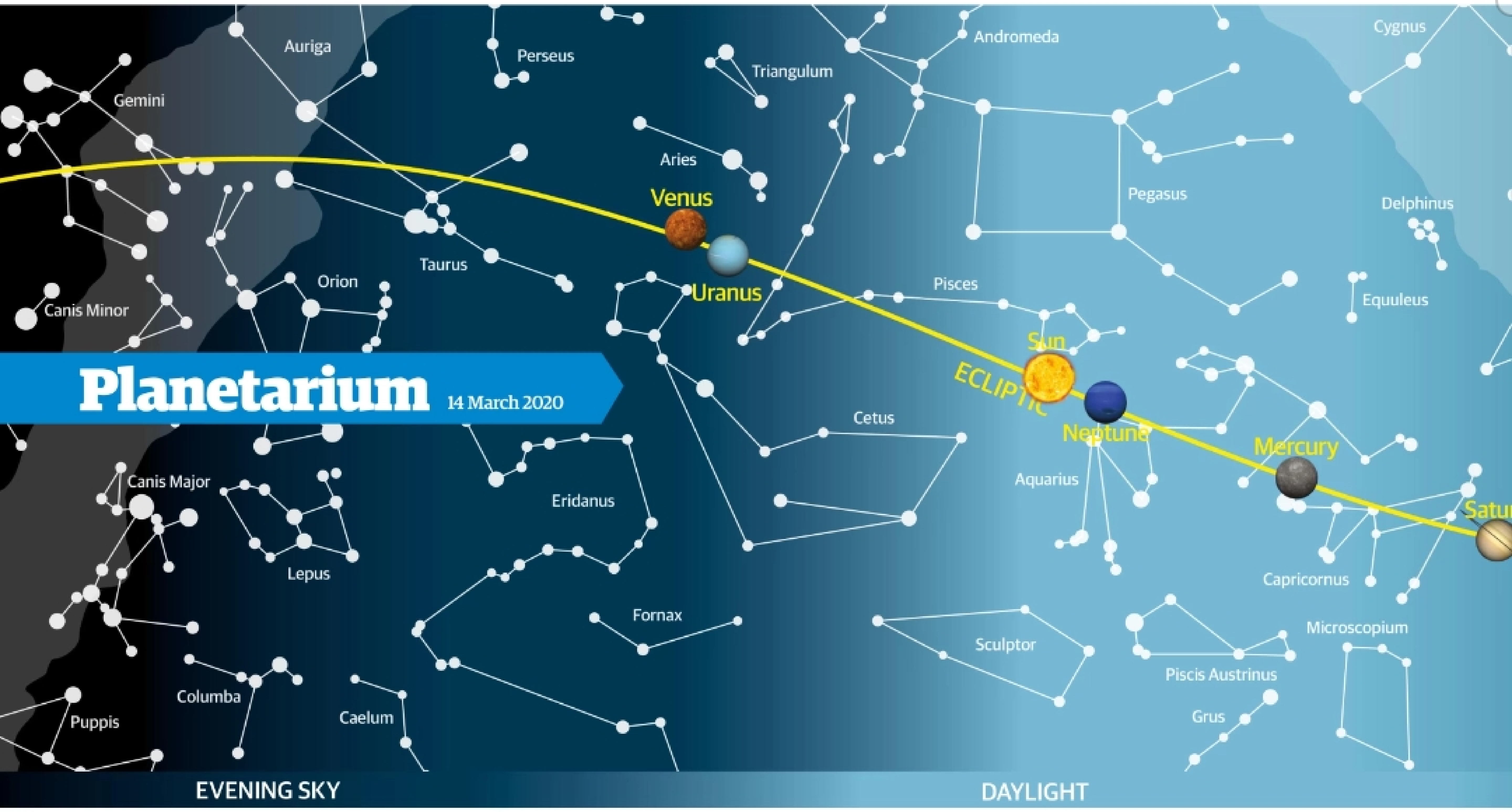
23 MAR 👁
Mercury reaches its greatest elongation in the dawn sky, shining brightly at +0.2

24 MAR 👁
Venus reaches its greatest elongation in the evening sky, shining brightly at -4.4

👁 Naked eye
∞ Binoculars
🔭 Small telescope
🔭 Medium telescope
🔭 Large telescope

Planetarium

14 March 2020



Moon calendar

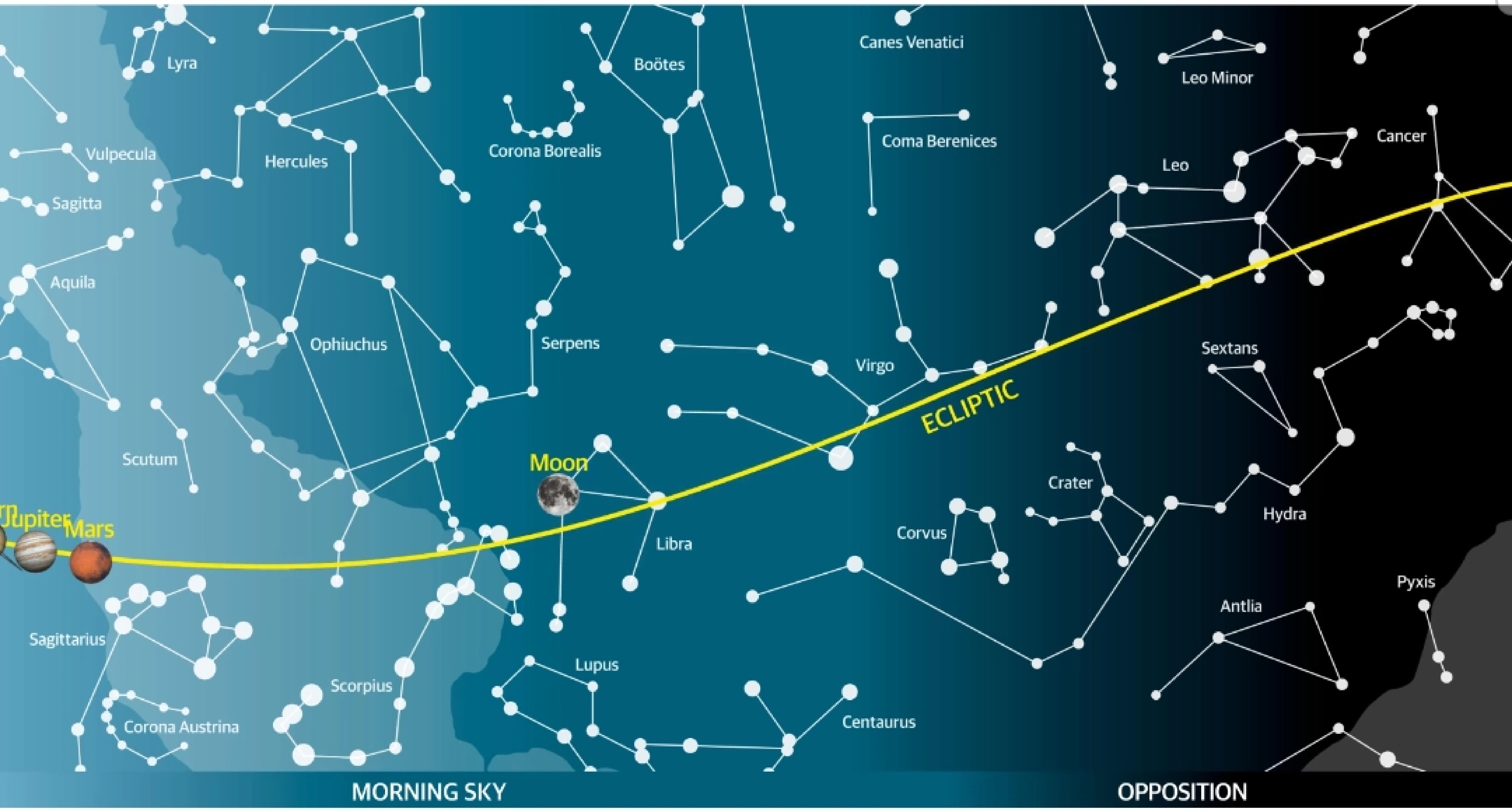
* The Moon does not pass the meridian on 9 March

			27 FEB 13.9% ▲08:37 ▼21:37	**28 FEB** 21.2% ▲08:53 ▼22:44	**29 FEB** 29.7% ▲09:11 ▼23:52	**1 MAR** 39.2% ▲09:33 ▼
2 MAR FQ 49.3% ▼01:00 ▲09:59	**3 MAR** 59.8% ▼02:09 ▲10:33	**4 MAR** 70.2% ▼03:15 ▲11:16	**5 MAR** 80.0% ▼04:15 ▲12:12	**6 MAR** 88.6% ▼05:06 ▲13:22	**7 MAR** 95.1%* ▼05:48 ▼14:41	**8 MAR** 99.0% ▼06:22 ▲
9 MAR --:--%* ▼06:49 ▲17:35	**10 MAR** 99.7% ▼07:13 ▲19:03	**11 MAR** 97.1% ▼07:35 ▲20:30	**12 MAR** 91.5% ▼07:57 ▲21:56	**13 MAR** 83.5% ▼08:20 ▲23:19	**14 MAR** 73.7% ▼08:47 ▲--:--	**15 MAR** 62.8% ▲00:39 ▼
16 MAR TQ 51.7% ▲01:53 ▼09:59	**17 MAR** 40.9% ▲02:57 ▼10:48	**18 MAR** 30.8% ▲03:50 ▼11:44	**19 MAR** 21.7% ▲04:32 ▼12:47	**20 MAR** 14.1% ▲05:05 ▼13:54	**21 MAR** 7.9% ▲05:31 ▼15:02	**22 MAR** 3.5% ▲05:53 ▼
23 MAR 0.9% ▲06:11 ▼17:16	**24 MAR** NM 0.2% ▲06:27 ▼18:22	**25 MAR** 1.4% ▲06:43 ▼19:29	**26 MAR** 4.4% ▲06:59 ▼20:35			

% Illumination
▲ Moonrise time
▼ Moonset time

FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

All figures are given for 00h at midnight (local times for London, UK)



Illumination percentage

	5 MAR	14 MAR	21 MAR	26 MAR
MERCURY	10%	30%	50%	60%
VENUS	60%	60%	50%	50%
MARS	90%	90%	90%	90%
JUPITER	100%	100%	100%	100%
SATURN	100%	100%	100%	100%

Planet positions

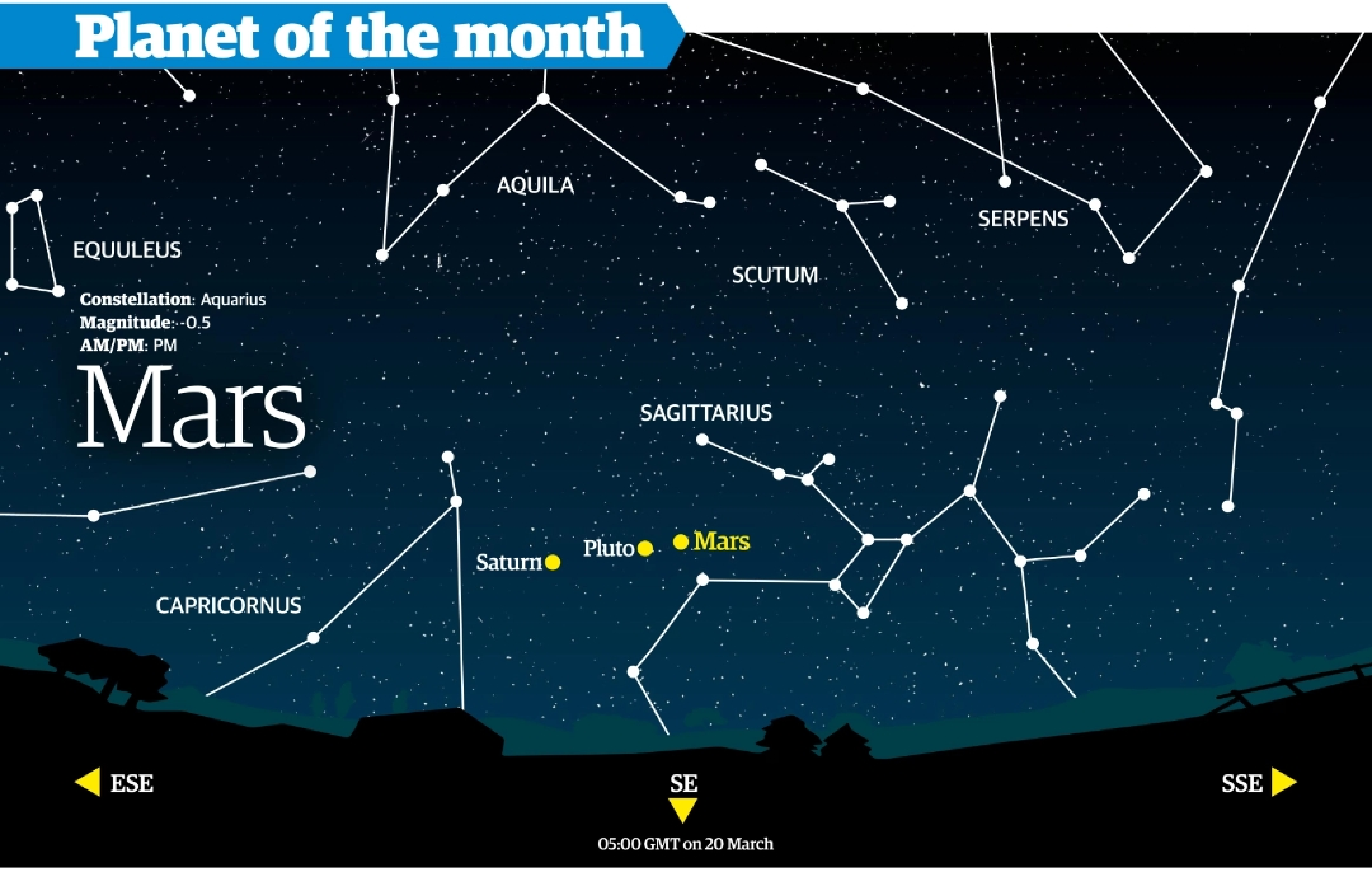
All rise and set times are given in GMT

	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	27 FEB	22h 24m 17s	-06° 00' 15"	Aquarius	5.2	06:25	17:32
	5 MAR	22h 02m 14s	-09° 09' 52"	Aquarius	2.1	05:52	16:26
	14 MAR	22h 02m 22s	-11° 22' 32"	Aquarius	0.6	05:28	15:39
	21 MAR	22h 20m 59s	-11° 07' 20"	Aquarius	0.2	05:18	15:31
	26 MAR	22h 40m 25s	-10° 02' 09"	Aquarius	0.1	05:12	15:37
VENUS	27 FEB	01h 19m 18s	+09° 18' 22"	Pisces	-4.2	08:01	21:44
	5 MAR	01h 47m 58s	+12° 40' 01"	Aries	-4.2	07:44	22:04
	14 MAR	02h 24m 38s	+16° 38' 47"	Aries	-4.3	07:23	22:28
	21 MAR	02h 52m 54s	+19° 24' 25"	Aries	-4.3	07:06	22:45
	26 MAR	03h 12m 50s	+21° 10' 13"	Aries	-4.4	06:55	22:57
MARS	27 FEB	18h 30m28s	-23° 36' 55"	Sagittarius	1.1	04:14	11:56
	5 MAR	18h 51m 32s	-23° 23' 11"	Sagittarius	1.1	04:06	11:52
	14 MAR	19h 18m 33s	-22° 50' 47"	Sagittarius	1.0	03:53	11:47
	21 MAR	19h 39m 26s	-22° 14' 27"	Sagittarius	1.0	03:43	11:44
	26 MAR	19h 54m 15s	-21° 42' 47"	Sagittarius	1.0	03:34	11:43
JUPITER	27 FEB	19h 21m 03s	-22° 07' 53"	Sagittarius	-2.0	04:54	12:57
	5 MAR	19h 26m 33s	-21° 57' 38"	Sagittarius	-2.0	04:31	12:36
	14 MAR	19h 33m 05s	-21° 44' 37"	Sagittarius	-2.1	04:01	12:09
	21 MAR	19h 37m 43s	-21° 34' 54"	Sagittarius	-2.1	03:37	11:47
	26 MAR	19h 40m 46s	-21° 28' 17"	Sagittarius	-2.1	03:19	11:31
SATURN	27 FEB	19h 58m 42s	-20° 39' 21"	Sagittarius	0.7	05:22	13:44
	5 MAR	20h 01m 32s	-21° 03' 28"	Sagittarius	0.7	04:56	13:20
	14 MAR	20h 04m 54s	-20° 22' 39"	Sagittarius	0.7	04:23	12:49
	21 MAR	20h 07m 15s	-20° 16' 10"	Sagittarius	0.7	03:58	12:25
	26 MAR	19h 58m 16s	-20° 40' 27"	Sagittarius	0.7	05:26	13:48

This month's planets

Mars, Jupiter and Saturn form a planetary parade in the morning sky this month, while Venus makes a dazzling entrance in the evening

Planet of the month



Constellation: Aquarius
Magnitude: -0.5
AM/PM: PM

Mars

05:00 GMT on 20 March

Mars, the Red Planet, is our Planet of the Month this month not because it is especially bright or easy to see, but because it will be taking part in a wonderful 'planetary parade' in the east before sunrise. Shining at a very respectable magnitude of 1.1 means Mars will be an easy naked-eye object, brighter than either of the stars Pollux or Deneb, so even if it wasn't part of that parade it would be worth looking at in its own right.

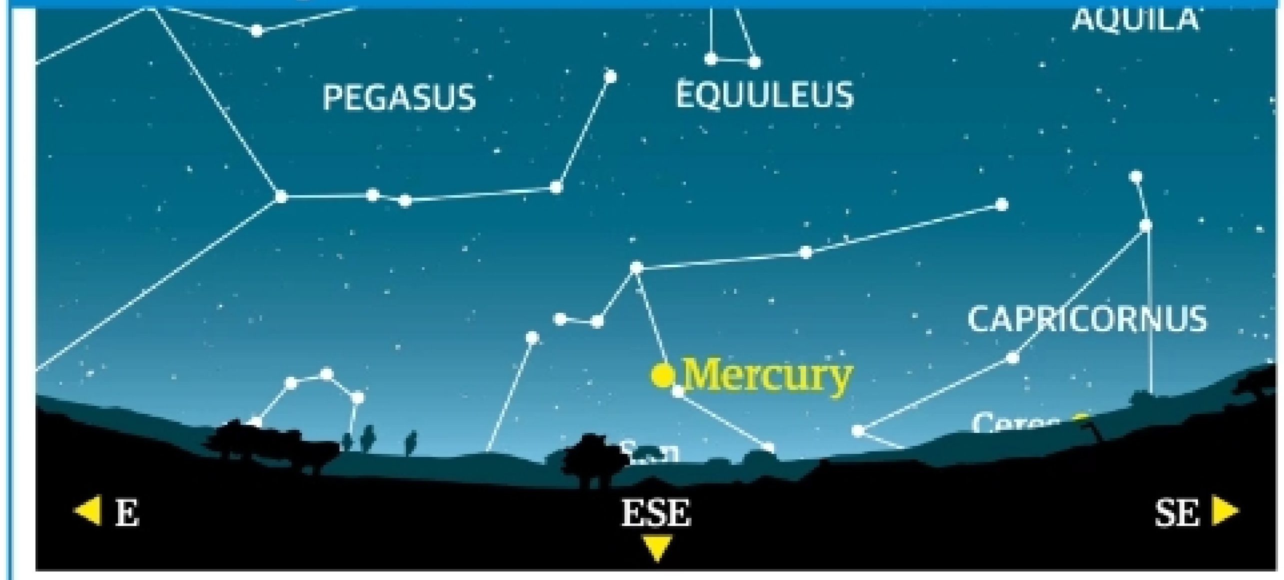
At the start of March Mars will be on the western, or right end of a long line of three naked-eye planets, with Jupiter and Saturn down to its lower left. By 12 March the trio of worlds will have bunched up closer together to form an Orion's Belt-like trio in the pre-dawn southeastern sky. Three mornings later, on 18 March, the situation will have changed quite dramatically: Mars will be shining very close to Jupiter – just three Moon widths away to its lower right – and a waning crescent Moon will be just two degrees away from the planetary pair. Grouped so close together, the three objects will make a stunning sight in the sky, one definitely worth looking at through a pair of binoculars, and a good chance to try out photographing it too – best results will be achieved with a DSLR on a tripod, but your phone's camera should pick them up too.

By 20 March the Moon will have left the party, but Mars and Jupiter will have moved even closer together. Less than a degree – or two Moon widths – apart, the pair will be a stunning sight in binoculars or a telescope's low-power eyepiece.

By 25 March the parade will look dramatically different again. Now Mars will be in the centre of the planetary parade, with Jupiter to its upper right and Saturn down to its lower left. All three worlds will be easily visible to the naked eye, and will look very attractive through binoculars before the brightening sky begins to wash them out.

As good as Mars will look during March, later this year Mars will be a lot more impressive. By the time it has moved into the evening sky it will be much closer to Earth, so it will look much brighter and higher too, an obvious orange-red 'beacon' in the sky, brighter than anything else around it. By then four missions should be on their way to Mars, one built by NASA, another by the European Space Agency, one from China and one from the United Arab Emirates. These will try to answer the question of if there ever was – or still is – life on the Red Planet.

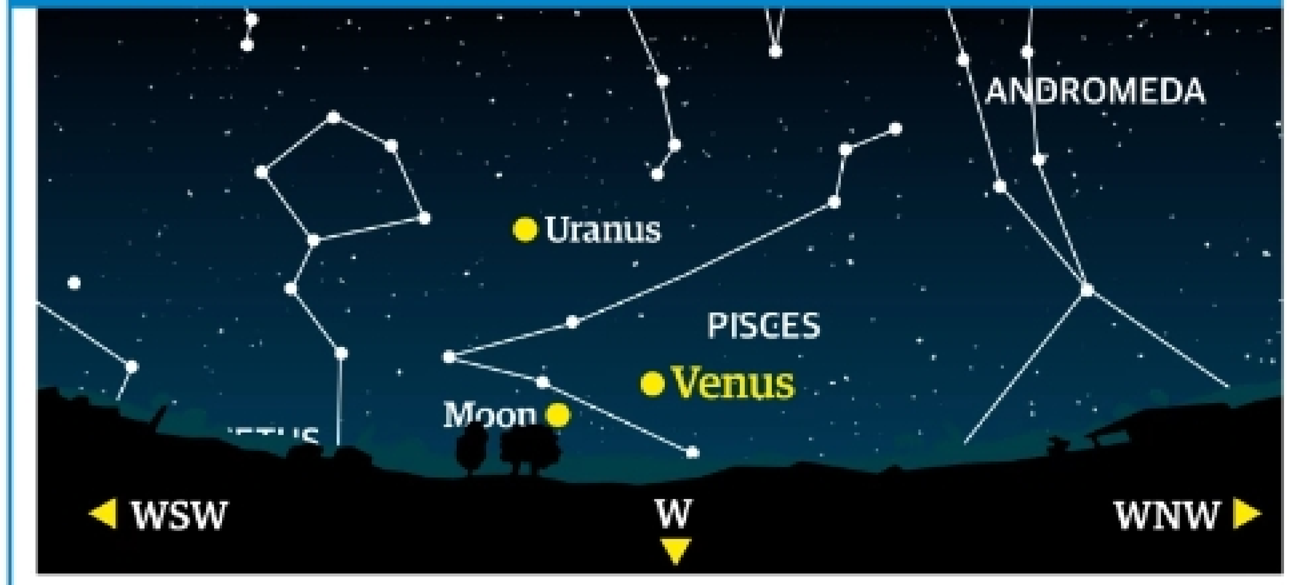
Mercury 07:00 GMT on 28 February



Constellation: Aquarius
Magnitude: 3.0
AM/PM: AM

Technically a 'morning star' visible before sunrise, shining at only magnitude 3.0 in a bright pre-dawn eastern sky, it will be too faint for most people to see with the naked eye. A pair of binoculars should pick it out if you sweep the sky, but you'll need a low, flat horizon in that direction if you're going to see it.

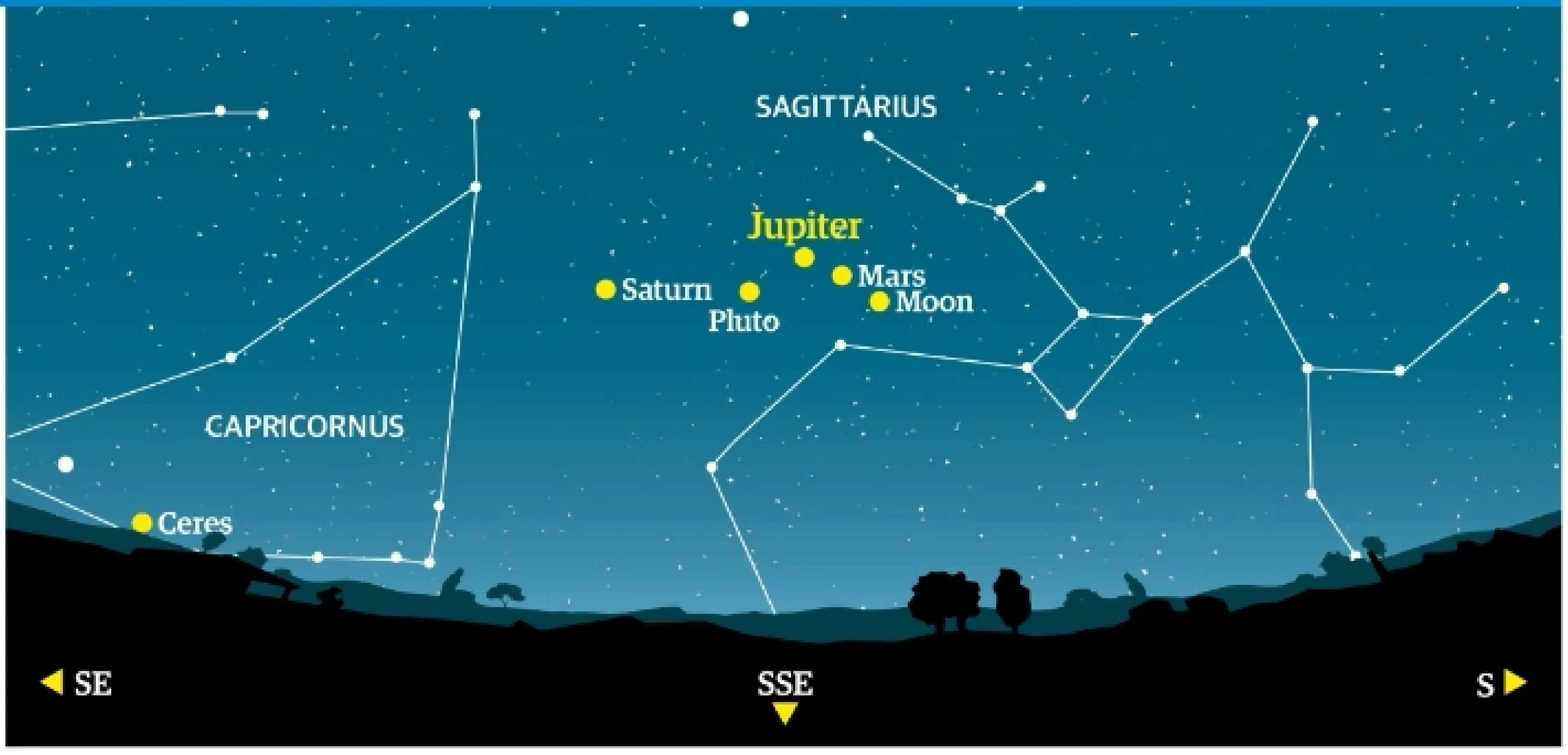
Venus 20:00 GMT on 27 February



Constellation: Pisces
Magnitude: -4.2
AM/PM: PM

This month the evening sky belongs to Venus; there's simply nothing as bright, or as beautiful. It sets several hours after the Sun, and you'll spot it high in the southwest as soon as half an hour after sunset, looking like a metallic silvery spark in the dusk. As the dusk deepens Venus will get brighter and more beautiful.

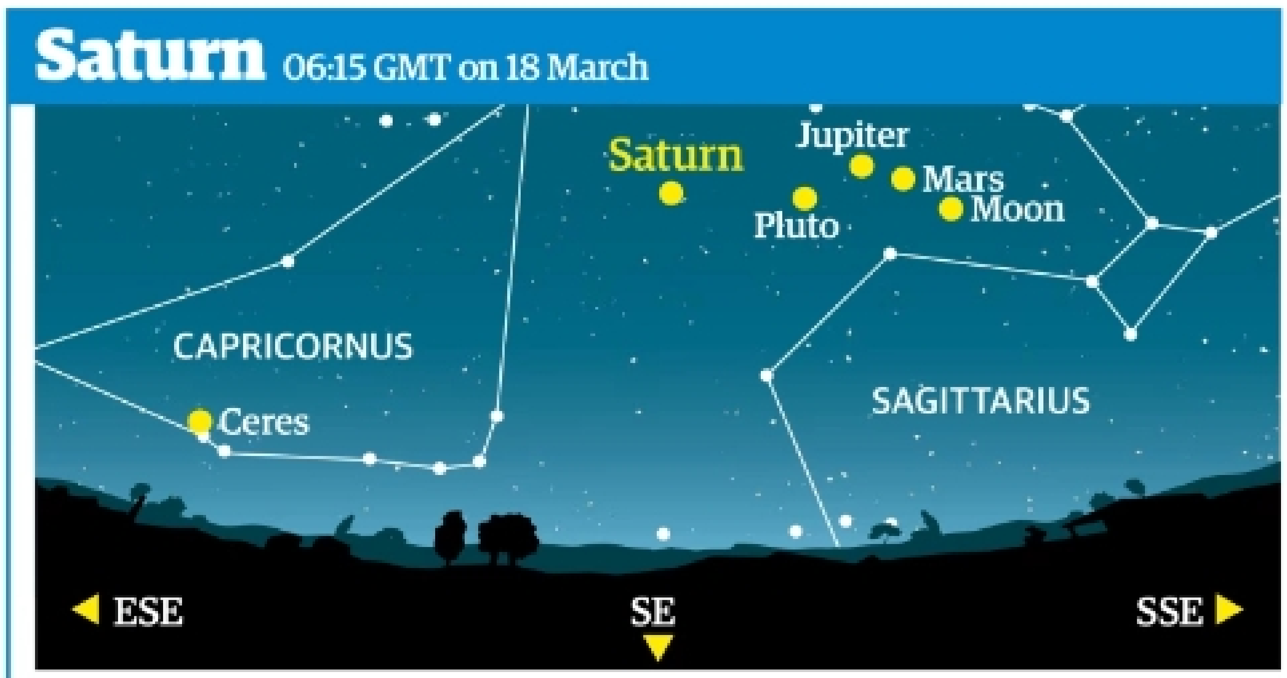
Jupiter 06:00 GMT on 18 March



Constellation: Sagittarius
Magnitude: -2.0
AM/PM: AM

Jupiter is a bright naked-eye 'morning star' this month, shining low in the southeast before sunrise. It will appear much brighter than its neighbours, Saturn and Mars. At the start of March Jupiter will be between the pair, and by the end of March will be to the upper right of them, still brighter than either. On the morning of 18 March a lovely waning crescent Moon will be shining very close to Jupiter and Mars, which will themselves be so close together they will look like a double star to the naked eye and through binoculars. Binoculars will show you Jupiter's four largest moons.

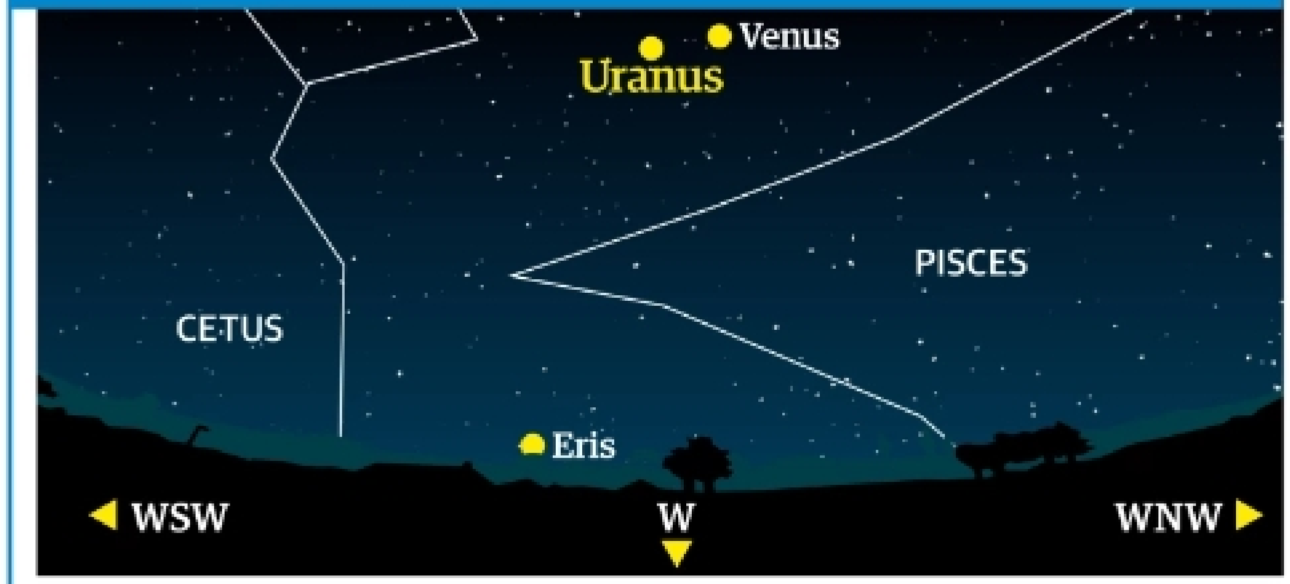
Saturn 06:15 GMT on 18 March



Constellation: Sagittarius
Magnitude: 0.7
AM/PM: AM

Saturn is another 'morning star' this month, clearly visible to the naked eye as a yellow-white 'star' low in the southeast before sunrise. Although a pair of binoculars is powerful enough to show you Titan, Saturn's largest moon, as a 'star' close to the planet, you will need a telescope to see Saturn's famous rings.

Uranus 20:00 GMT on 8 March



Constellation: Aries
Magnitude: 5.9
AM/PM: PM

The most exciting thing about Uranus this month is that it will be found very close to Venus in the sky. At magnitude 5.9 Uranus is technically a naked-eye object, but this month the planet is already so low in the west after sunset that it will be in a twilight sky, so very hard to see without the assistance of binoculars.

© NASA

Top tip!

Make sure you look for Herschel when it is near the terminator – that's when it will look its best!

Moon tour

Herschel

Explore a crater near the Moon's centre, named after an important astronomer

The Herschels probably discovered, observed and recorded more planets, moons, comets and other objects than any other family, and today their achievements are rightly honoured on worlds and satellites across the Solar System, with craters that bear their family or individual name. Our Moon Tour destination this month is one of those craters – a small crater named after William Herschel, brother of Caroline and father of John.

When seasoned lunar observers try to help newcomers locate a feature on the Moon, they usually describe it in relation to its position either within a circle or around a clock face. Mare Crisium is well known as the 'dark patch to the top right of the Moon', just as the crater Tycho is often referred to as 'the bright spot near the bottom with bright lines streaking away from it'. If you were being helped to find the crater Herschel, you'd probably be told it is almost bang in the centre.

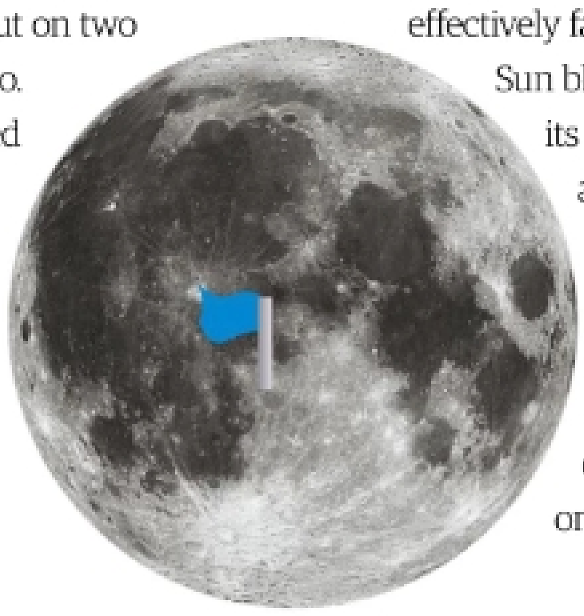
More accurately though, Herschel can be described as being just above the huge crater Ptolemaeus, the northernmost member of the great triple crater chain of Ptolemaeus, Alphonsus and Arzachel. But where Ptolemaeus is a true celebrity feature, Herschel is average in every way. Its diameter of 39 kilometres (24 miles) is quite respectable, but not extraordinary; it is so shallow it is more of an upturned bowl – or dinner plate – than a gaping pit; it is roughly circular in shape; its inner walls have some terraces and ledges, but they are fewer and less fractured and raggedy than many other craters of its size; its central peak is eroded and smoothed rather than jagged and sharp and a mere handful of smaller craters can be seen spattered across its floor.

The appeal of observing this crater lies not in peering into it through an eyepiece and seeing subtle and fine details within or around it, but in contemplating the person it was named after. William Herschel is best known, of course, for discovering the planet Uranus in 1781, but he did much more than that. He also discovered Enceladus and Mimas, two of Saturn's huge family of icy moons, conducted detailed surveys of the sky and made measurements of variable stars. It's no surprise that he is honoured on not just the Moon, but on two of the Solar System's other worlds too.

On Mars an enormous crater called 'Herschel' with a diameter of more than 300 kilometres (186 miles) can be found in the southern hemisphere in Mare Tyrrhenum, its floor rippled with enormous dunes of dark dust sculpted by the Martian winds.

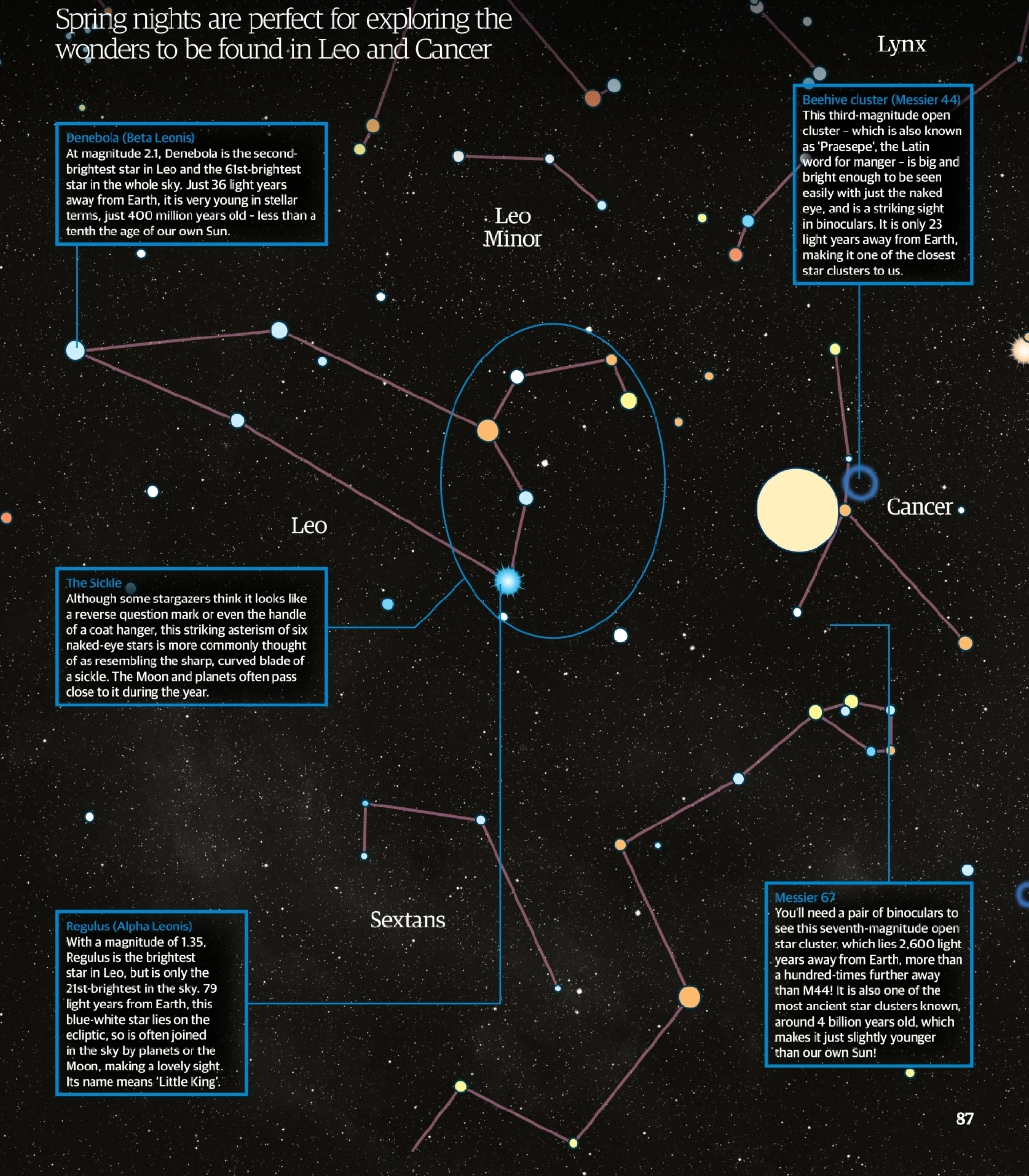
But the most famous 'Herschelean' crater can be found on Mimas, a moon that William Herschel himself discovered. This crater has a diameter of almost 140 kilometres (87 miles), making it ten-times wider than the Herschel crater we see on our Moon and a third as wide as Mimas itself.

So when can you see this lunar Herschel crater for yourself? At the start of our observing period Herschel cannot be seen, as it is deep in shadow. Herschel won't appear until the evening of 3 March, when the terminator, the line between night and day, approaches it. Then the crater's walls and central peak will become visible. By 4 March the crater will be fully illuminated, and from then until around 8 March the crater will be a very attractive sight in even a small telescope's high-power eyepiece. But when the Moon reaches full on 10 March it will effectively fade into the background; with the Sun blazing overhead the shadows cast by its walls and central peak will vanish, and Herschel will become just a dark circle. By 15 March the terminator will approach the crater again, and its shadows will return, but only until 17 March, when the crater will be plunged into darkness once more.



Naked eye & binocular targets

Spring nights are perfect for exploring the wonders to be found in Leo and Cancer



Denebola (Beta Leonis)
At magnitude 2.1, Denebola is the second-brightest star in Leo and the 61st-brightest star in the whole sky. Just 36 light years away from Earth, it is very young in stellar terms, just 400 million years old – less than a tenth the age of our own Sun.

Beehive cluster (Messier 44)
This third-magnitude open cluster – which is also known as 'Praesepe', the Latin word for manger – is big and bright enough to be seen easily with just the naked eye, and is a striking sight in binoculars. It is only 23 light years away from Earth, making it one of the closest star clusters to us.

The Sickle
Although some stargazers think it looks like a reverse question mark or even the handle of a coat hanger, this striking asterism of six naked-eye stars is more commonly thought of as resembling the sharp, curved blade of a sickle. The Moon and planets often pass close to it during the year.

Regulus (Alpha Leonis)
With a magnitude of 1.35, Regulus is the brightest star in Leo, but is only the 21st-brightest in the sky. 79 light years from Earth, this blue-white star lies on the ecliptic, so is often joined in the sky by planets or the Moon, making a lovely sight. Its name means 'Little King'.

Messier 67
You'll need a pair of binoculars to see this seventh-magnitude open star cluster, which lies 2,600 light years away from Earth, more than a hundred-times further away than M44! It is also one of the most ancient star clusters known, around 4 billion years old, which makes it just slightly younger than our own Sun!

Deep sky challenge

Intriguing galaxies and sparkling clusters

Spring is finally here, so now's the time to go hunting in Coma Berenices and Canes Venatici

As winter turns to spring the very nature of the night sky changes. Gone are winter's bright stars, bold constellations and obvious deep-sky delights such as the Orion Nebula, the Pleiades and open cluster M35. Replacing them are subtler constellations drawn with dimmer, less-obvious stars, and a host of deep-sky objects that are as distant as they are faint.

Apart from the beautiful globular cluster M53, which is always worth a look on a clear night, this month's challenges are galaxies dozens of light years from Earth. They lie in two of the most overlooked constellations – Canes Venatici and Coma Berenices. All are lovely sights in large telescopes and deserve to be seen just as much as winter's more famous 'celebrity' features such as the Orion Nebula and Horsehead Nebula. Indeed, NGC 4565, the Needle Galaxy, is one of the loveliest galaxies in the sky, far more impressive than many much better-known edge-on galaxies such as M82.

Messier 53

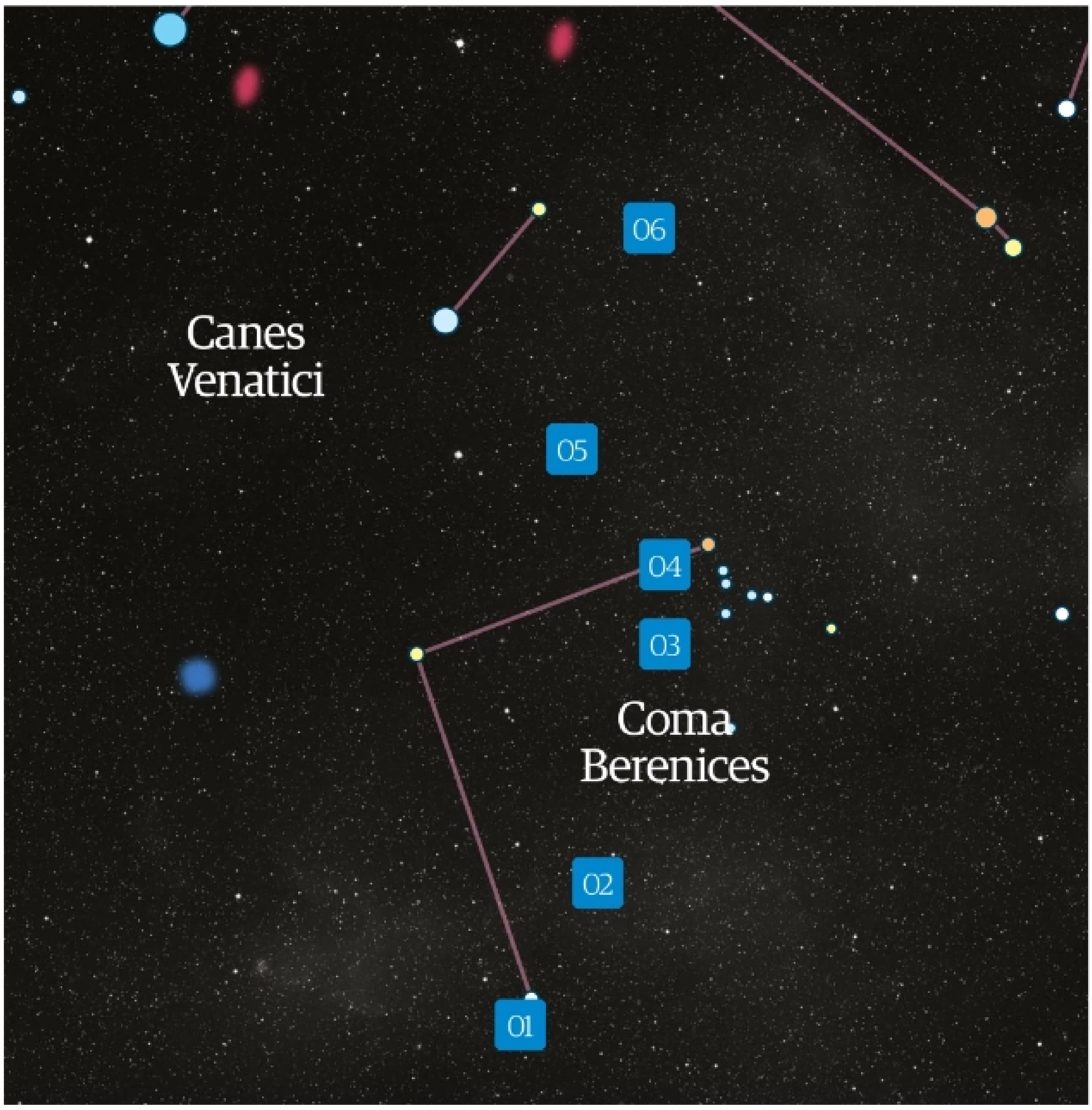
© NASA;ESA

Black Eye Galaxy (Messier 64)

© NASA;ESA

The Whale Galaxy (NGC 4631)

© NASA/ESA



1 Messier 53

At magnitude 7.6 this globular cluster is bright enough to be seen in small telescopes, but larger instruments will resolve its small, hazy ball into a mottled disc of stars.

2 The Black Eye Galaxy (Messier 64)

A dark lane of dust curved around this distant spiral galaxy gives it its nickname, but you will only appreciate its 'black-eye' appearance through the high-power eyepieces of large telescopes.

3 The Needle Galaxy (NGC 4565)

This is one of the most prominent and famous edge-on galaxies in the sky. Large telescopes best show its bright core silhouetted against its dark disc.

4 NGC 4559

The spiral arms of this obliquely viewed ninth-magnitude galaxy are tightly wound, so hard to see properly, but a large telescope will reveal their star-forming regions as brighter patches.

5 The Whale Galaxy (NGC 4631)

This ancient globular cluster is visible even in small telescopes as an out-of-focus star. Larger instruments reveal its mottled core.

6 The Silver Needle Galaxy (NGC 4244)

You'll need a large telescope, powerful eyepiece and a perfect sky to see this edge-on spiral galaxy - even then it will only look like a pale, thin, ghostly streak of grey with a slightly brighter core.

STARGAZER

The Northern Hemisphere

Orion fades to the southwest while Leo climbs from the east

Leo (the Lion) takes pride of place in the night sky, cutting a regal figure as its leading star - hot, blue Regulus - shines at magnitude 1.36, an unmissable sight. Galaxies are also in abundance here - from the spiral arms of Messier 95 to the featureless, yet prominent form of Messier 105 - as well as a selection of binary stars, including Rho Leonis.

Leo is bordered by Cancer, Coma Berenices, Crater, Hydra, Leo Minor, Lynx, Sextans, Ursa Major and Virgo, the latter of which also offers a selection of galaxies to be enjoyed. If your interests lie in tracking down nebulae and star clusters, head over to the Great Bear for the Owl Nebula, or seek out the Beehive Cluster, also known as Praesepe, in the Crab.

Using the sky chart

This chart is for use at 22:00 (GMT) mid-month and is set for 52° latitude.

01 Hold the chart above your head with the bottom of the page in front of you.

02 Face south and notice that north on the chart is behind you.

03 The constellations on the chart should now match what you see in the sky.

Magnitudes

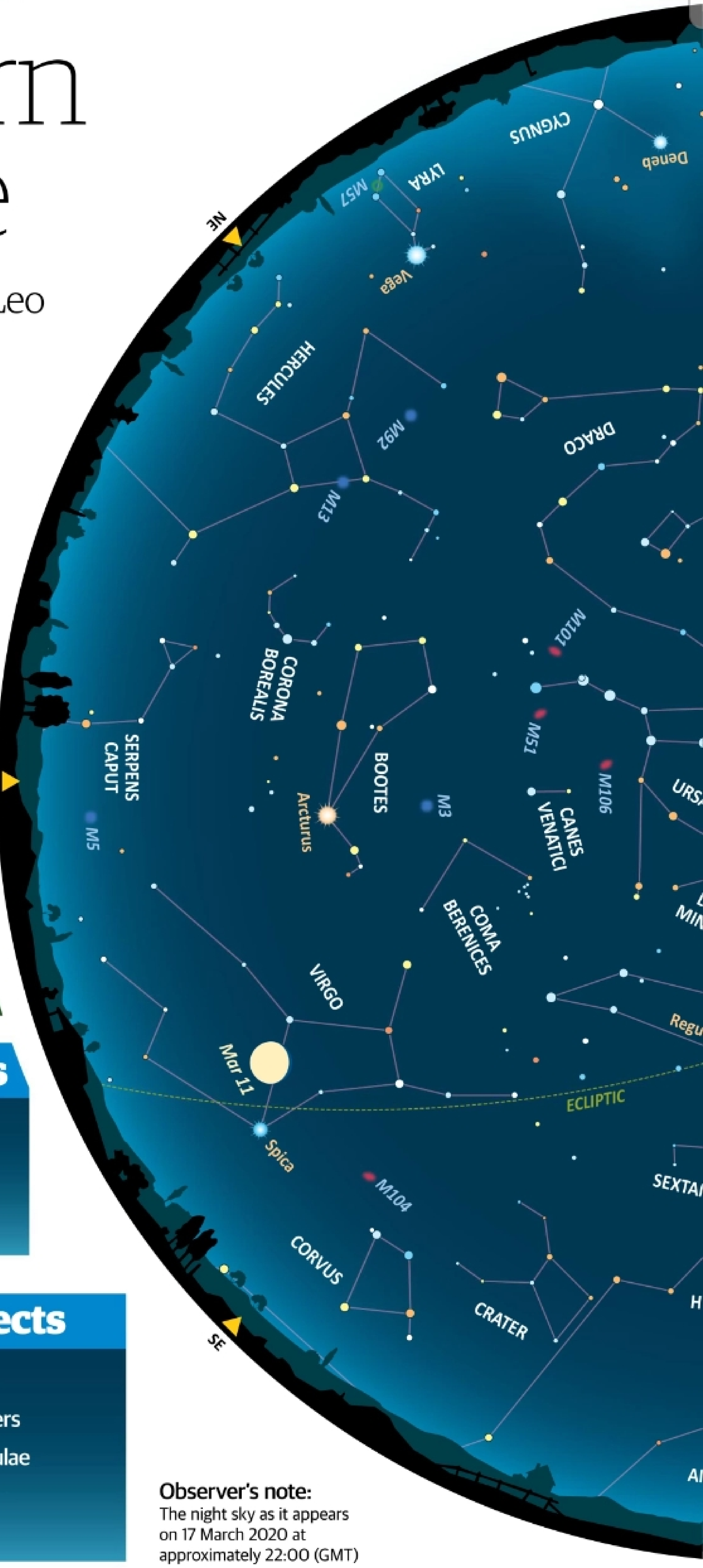
- ● Sirius (-1.4)
- ● -0.5 to 0.0
- ● 0.0 to 0.5
- ● 0.5 to 1.0
- ● 1.0 to 1.5
- • 1.5 to 2.0
- • 2.0 to 2.5
- • 2.5 to 3.0
- • 3.0 to 3.5
- · 3.5 to 4.0
- · 4.0 to 4.5
- · Fainter
- ⊙ Variable star

Spectral types

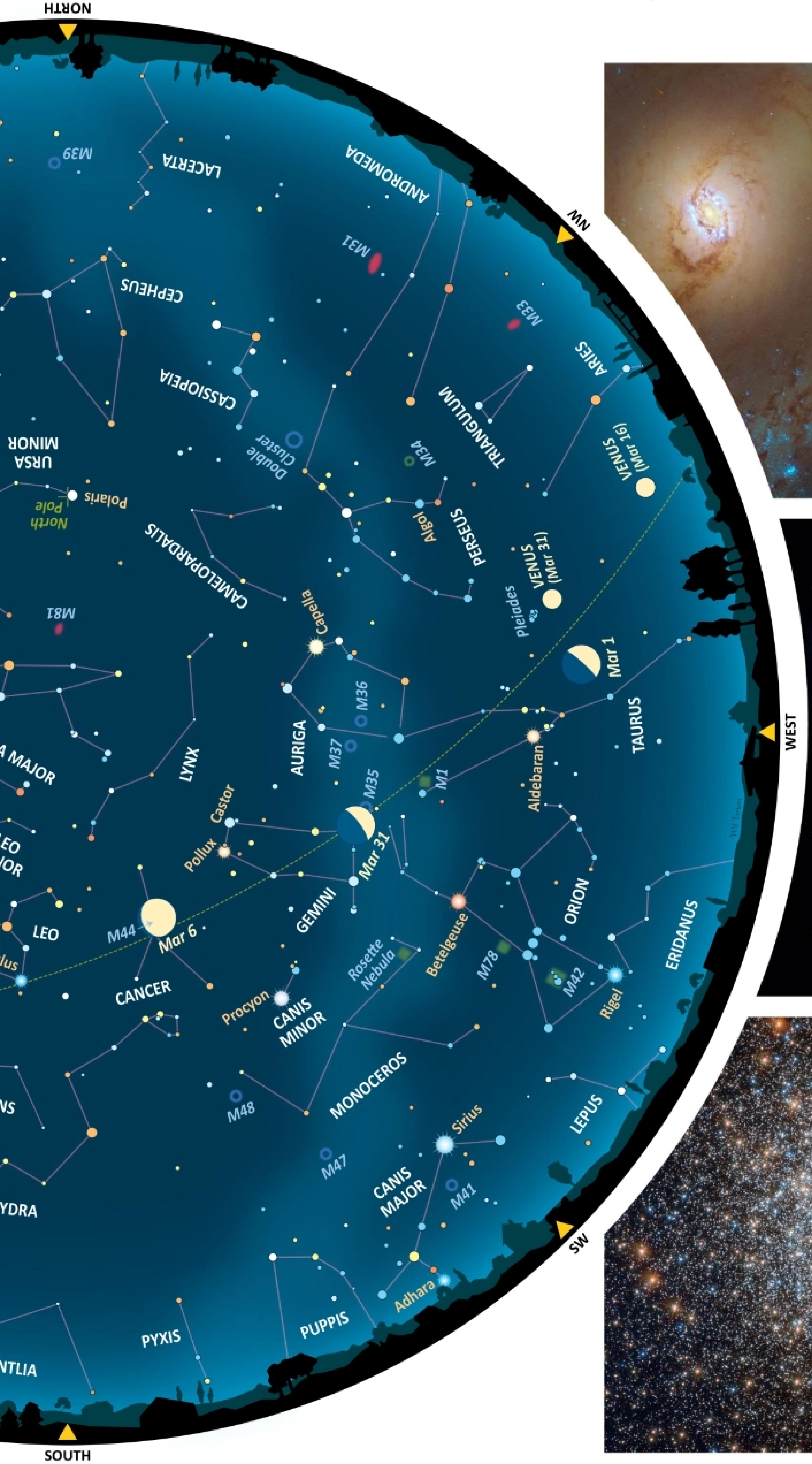
- ● O-B
- ● A
- ● F
- ● G
- ● K
- ● M

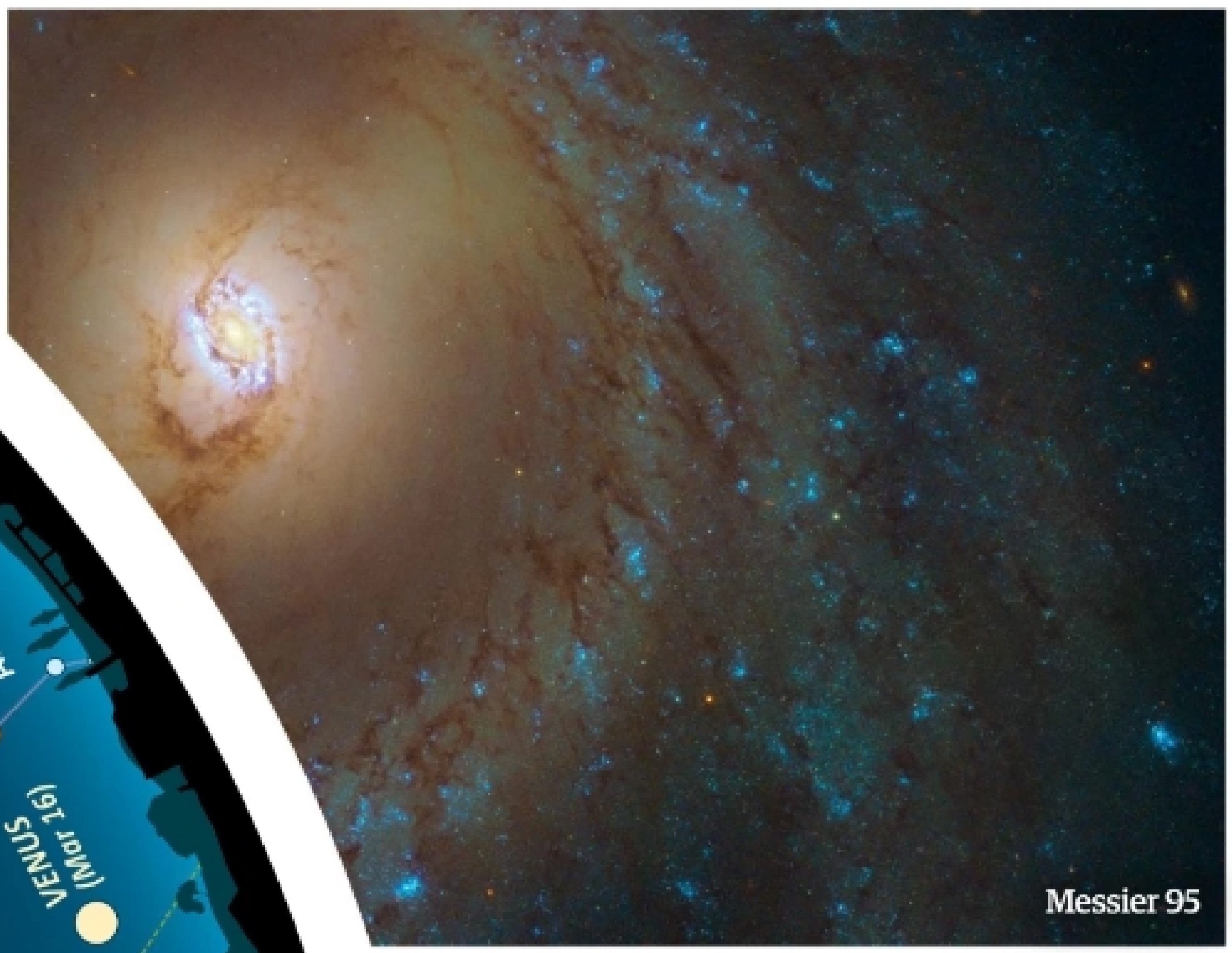
Deep-sky objects

- ○ Open star clusters
- ● Globular star clusters
- ■ Bright diffuse nebulae
- ○ Planetary nebulae
- ● Galaxies



Observer's note:
The night sky as it appears on 17 March 2020 at approximately 22:00 (GMT)





Messier 95

© ESA/Hubble & NASA

Messier 66

© ESO

Messier 3

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Astroshots of the month

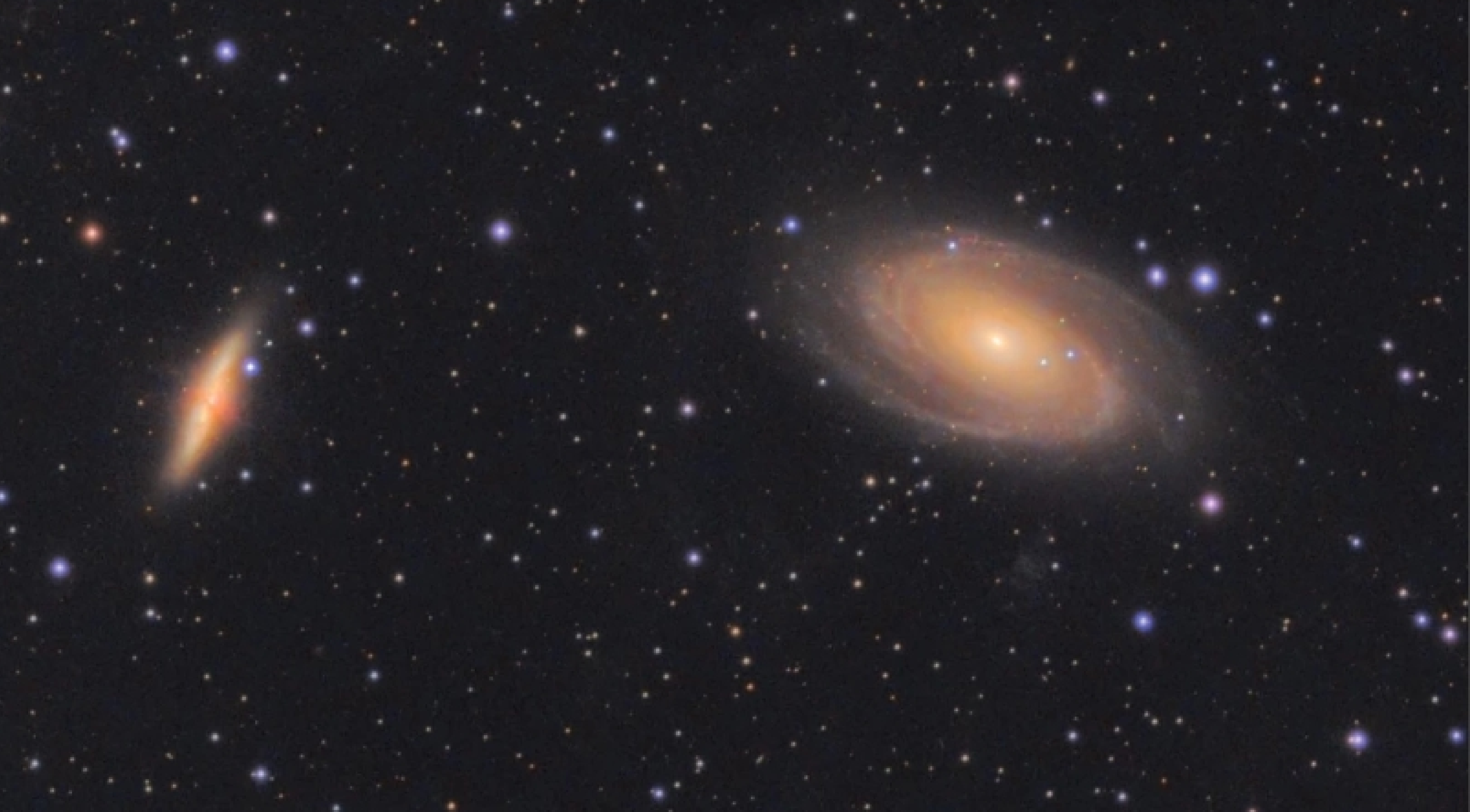
Send your astrophotography images to **space@spaceanswers.com** for a chance to see them featured in **All About Space**

Jeff Johnson

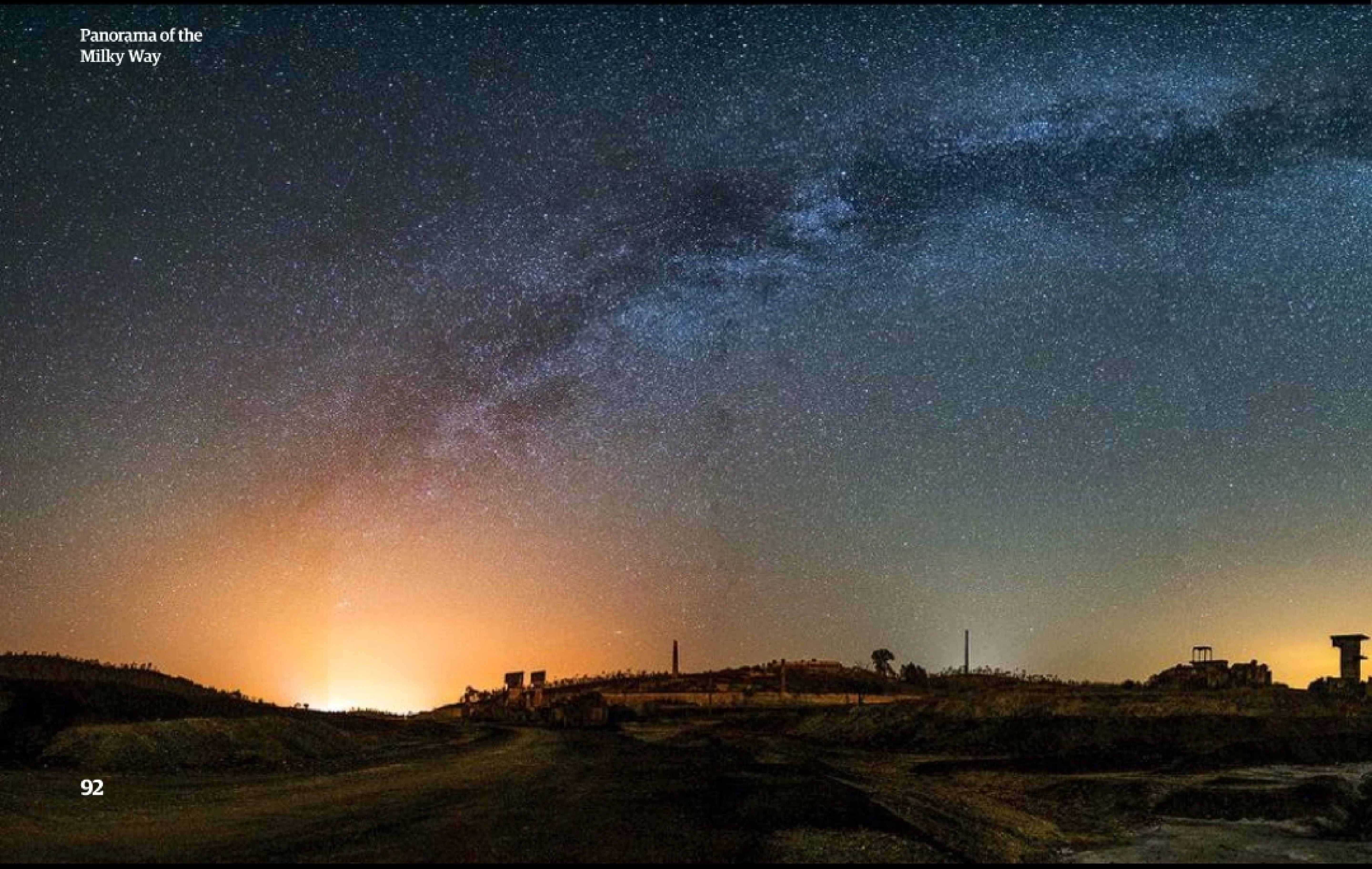
Las Cruces, New Mexico

Telescope: Takahashi TOA-130F refractor

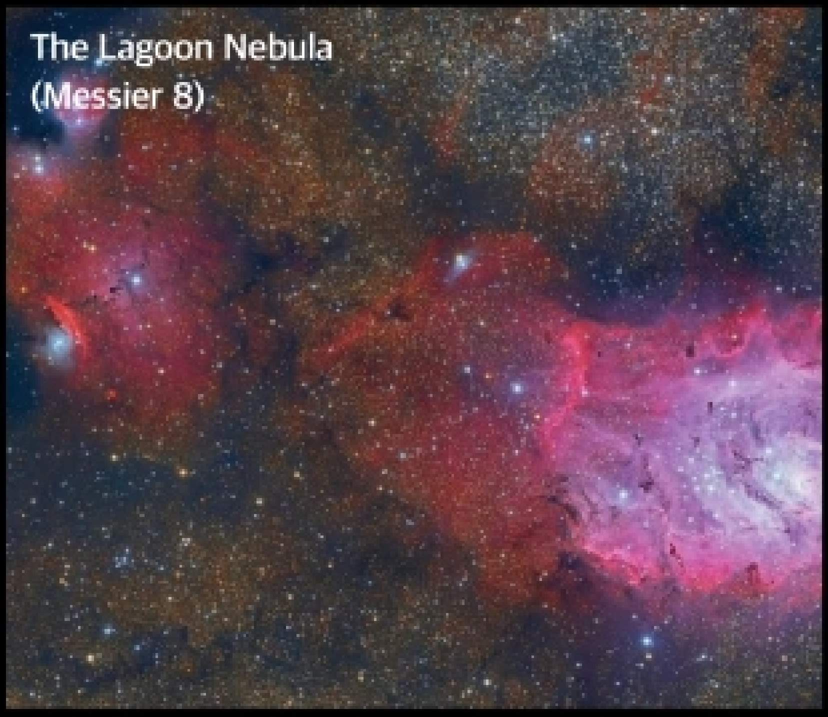
"I have a long love of astronomy and have observed the night sky for many years with binoculars and a telescope from the age of ten. I did my first 'real' astrophotography in 1996 when I used a 35mm SLR camera to take photos of Comet Hyakutake. I took a tripod out into the desert here in Las Cruces and just experimented with exposures. Later I bought a 10" Dobsonian for viewing, and within a week was taking pictures through the eyepiece for fun. Within a few more weeks, I knew I wanted to get serious with astroimaging."



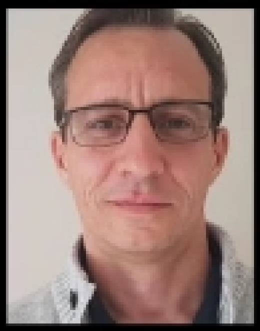
Messier 82 and Messier 81



Panorama of the Milky Way

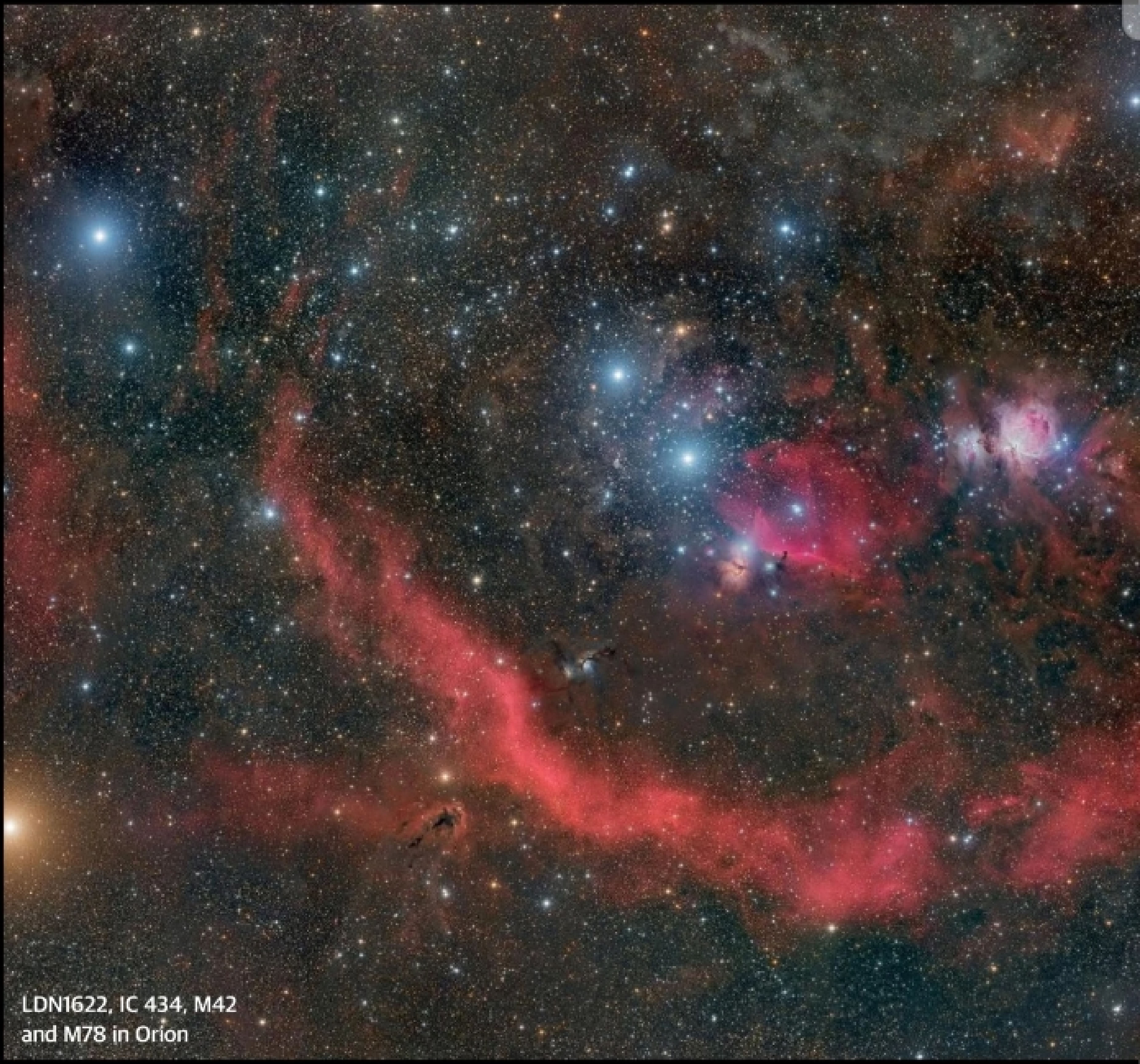

The Lagoon Nebula (Messier 8)

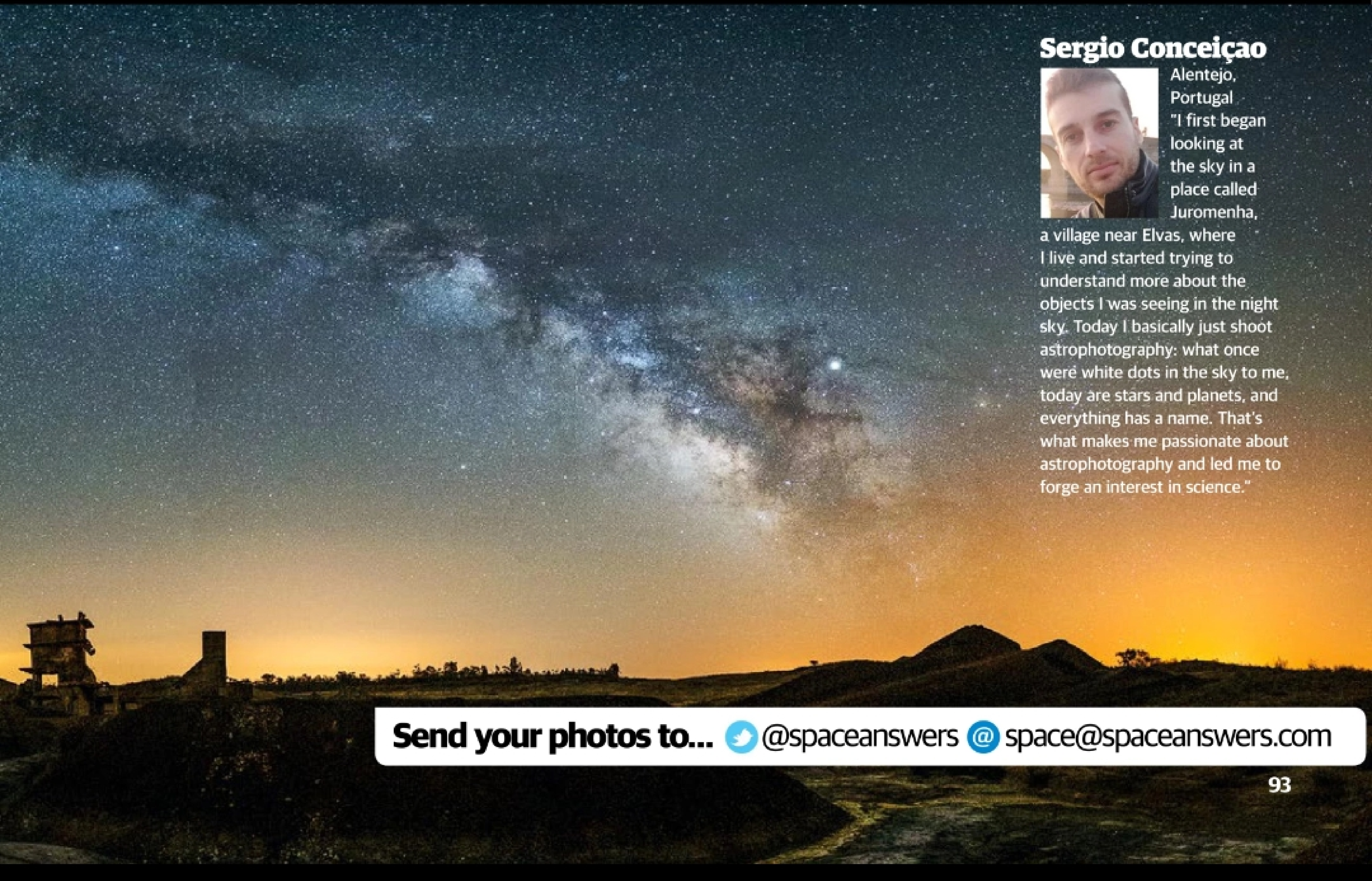
Patrick Gilliland



Worcestershire, UK
Calar Alto, Spain
Telescope: Officina Stellare RH 200 Astrograph, Borg 125 refractor, Takahashi 106, Astro-Physics AP305 Astrograph

"I have always had an affinity with dark nights since a holiday as a child, sitting looking in amazement at all of the stars of the Milky Way. In recent years I decided to get more involved in astronomy and later embarked on a hobby in astrophotography. I have begun a degree in astronomy and planetary science to better understand what I image."


LDN1622, IC 434, M42 and M78 in Orion



Sergio Conceiçao

Alentejo, Portugal

"I first began looking at the sky in a place called Juromenha, a village near Elvas, where I live and started trying to understand more about the objects I was seeing in the night sky. Today I basically just shoot astrophotography: what once were white dots in the sky to me, today are stars and planets, and everything has a name. That's what makes me passionate about astrophotography and led me to forge an interest in science."

Send your photos to... @spaceanswers space@spaceanswers.com

Olivon T800

With its sturdy outer armour combined with nitrogen gas-filled optics, this spotting scope is ideal for observing while staying protected from dew

Telescope advice

Cost: £379.99 ($484.40)
From: Optical Hardware Ltd
Type: Spotting scope
Aperture: 3.15"
Focal length: 18.9"

Best for...

- Intermediate
- Small budgets
- Planetary viewing
- Lunar viewing
- Deep-sky objects

The spotting scope is an instrument that's not very well associated with stargazing – it is most commonly used by the avid nature watcher who takes great delight in observing birds and other forms of wildlife. Given our experience with the T800 though, we found it to be an ideal companion for observing the night sky, in particular the Moon and notable star clusters, including the fine globular cluster Messier 7 in the constellation of Scorpius, close to the 'stinger' of the Scorpion.

Taking the spotting scope out of its box, we admired the care that had been put into packaging it: the box is sturdy and there is plenty in the way of padding to ensure that the instrument is sufficiently protected. The T800 comes with a protective case as well as a 20-60x zoom eyepiece. In order to get a steady view, you'll need a suitable tripod, something that unfortunately needs to be purchased separately. If you do not own a tripod then we strongly recommend that you purchase the T800 either with a TR150-10 tripod included in the package (£419.99/$535.34) or complete with a TR154-11 tripod (£489.99/$624.49).

The spotting scope has a very versatile 1.25" eyepiece holder that makes it ideal for use with astronomical eyepieces. The T800 has been manufactured to be waterproof, allowing nature lovers to watch wildlife in a variety of conditions, and features a fully waterproof, rubber-coated body to protect the aluminium body and optics. For that added security there is also nitrogen fog-proofing inside the armour. Astronomers know all too well about the condensation and dew that a change in temperature can cause observations and the damage to the coating on the objective lens and optical system if it isn't removed carefully. The T800, despite its body armour, is also quite light.

During our review, we were treated to the show that June's planets put on at dusk: Venus and Jupiter were in the process of drawing ever closer together and a waxing crescent Moon wasn't too far behind them in the western sky. The sight was spectacular to the unaided eye, but we were keen to test the T800's mettle on these objects. Starting at the Moon, we took advantage of the terminator, which played up several of the lunar surface's

Left: A 20-60x zoom eyepiece and a protective case are supplied with the spotting scope, but other required pieces of kit must be bought separately

The optical system features a BAK4 prism and a multi-coated lens for clear and crisp views. However, we did receive a degree of glare when observing bright targets

craters - Hipparchus, Halley, Klein and Faraday were revealed beautifully in the light and shadows in the T800's field of view. The full multi-coated lens, along with the BAK4 prism, ensured clear and crisp views across a very good proportion of the field of view using the high-quality zoom eyepiece. This is something that can often disappoint with cheaper spotting scopes. Operation of the zoom eyepiece is smooth, similarly with the twist eye cup, which has very good eye relief for those with or without glasses. The angled orientation of the spotting scope made for very comfortable viewing.

When it came to removing the zoom eyepiece, it did take a degree of effort initially. However, despite this, we were glad of the secure fit. The same could be said for when we slotted 1.25" telescope eyepieces into the spotting scope, and we appreciated the snugness. With our selection of astronomical eyepieces we had the option of increasing the magnification and also obtaining a wider angle of the field of view, making the spotting scope ideal for obtaining larger star fields and star clusters, as well as bright Solar System targets and bright nebulae.

Leaving the waxing crescent Moon, we slewed to Jupiter and Venus. In our field of view, we couldn't wait to observe the brighter of the pair, Venus, which shone at a magnitude of -4.4. The second planet from the Sun appeared as a bright disc, devoid of any detail, as expected. Since the target was bright there was a touch of glare around the object, but otherwise the view was pleasing enough. Turning our attention to Jupiter, we had much of the same - an obvious disc with a degree of glare, yet an otherwise steady and clear view. The Galilean moons - Io, Ganymede, Europa and Callisto - could be seen as points of light either side of the gas giant. We couldn't see a great deal of detail on the planet, however. Finding our way around the night sky was made slightly more difficult without a finderscope - something that many beginners to astronomy will more than likely find frustrating.

With clouds beginning to cover the sky, we quickly left the planetary conjunction and headed over to the open cluster Messier 7 in the constellation Scorpius. The member stars popped into view as impressive white, clear and crisp points of light. Several stars in the cluster appeared to take on a slight orange-red colour, which gave the cluster a beautiful two-toned appearance.

The T800 is an ideal instrument for those with an interest in both nature and astronomy that's limited to the brighter targets. If you're solely an astronomer or someone who is just learning your way around the night sky, then you are better off purchasing a pair of binoculars or a telescope that comes as a more complete package. However, if you're looking for an instrument that's easy to carry and that compliments your existing kit, then the Olivon T800 is certainly worth a look.

Above: The Olivon T800's 1.25" eyepiece holder accepts astronomical eyepieces, making it ideal for observing bright night-sky targets

Left: The Olivon T800 features a fully waterproof, rubber-coated body to protect the optics

"Craters were revealed beautifully in the light and shadows in the T800's field of view"

In the shops

The latest books, apps, software, tech and accessories for space and astronomy fans alike

Book 50 Things to See in the Sky

Cost: £9.99 (approx. $12.97)
From: Penguin Random House

A beautifully presented, practical guide to 50 sights in the skies above us complete with a glow-in-the dark front cover. Explained with fascinating, easy-to-understand commentary from astrophysicist and science communicator Sarah Barker and illustrated throughout with captivating drawings by Maria Nilsson, each guide helps you locate an incredible sight.

The book is divided into three main sections, and whether you use the naked eye, a telescope or fall into a black hole of online research, you'll discover the limitless wonder of the skies, from otherworldly phenomena on Earth like Sun dogs to planets, moons, stars, lunar craters and galaxy clusters. You can learn how navigators travelled in the past by finding the North Star, say hello to our astronauts and learn how to spot the International Space Station, see red supergiant star Betelgeuse and find out more about solar eclipses.

The book also includes advice on ideal conditions for observing the stars through telescopes and binoculars and navigating the skies. With extra tips and a rundown of useful tools, you'll find everything you need to get out there and look up!

Software Celestia

Cost: Free
From: celestiaproject.net

Bringing the universe to your computer, Celestia offers a full three-dimensional representation of planets, stars and galaxies, and is based on the Hipparcos catalogue of more than 100,000 stars. What we enjoyed the most about this software is that you're not shackled to Earth – Celestia allows you to whizz off in any direction you feel like going, at any speed, whether it's a leisurely stroll or travelling at the speed of light. While the graphics are impressive for a free software, we noted that due to computer memory limitations Celestia didn't go out much further than 16,000 light years. As a result, we couldn't investigate the 'entire universe' through our computer screens.

Celestia runs on a variety of operating systems including Windows, Linux and Macintosh and features a guided tour of the Solar System, an eclipse finder, an updated exoplanet database and an International Space Station tracker. The specially made Celestia website features a user manual, showing you how to use the astronomy software – we recommend downloading this and taking the time to read it. Celestia isn't very user friendly, but once you've cracked how to use it, it's perhaps one of the most powerful pieces of software you'll ever get to operate. If you find that you've explored what Celestia has to offer, there's the opportunity to download dozens of easy-to-install add-ons with more objects to explore in your virtual universe.

App SkySafari 6 Pro

Cost: £26.99 / $39.99 **From:** iTunes

We have never been more impressed with an astronomy app than we are with SkySafari 6 Pro, which features 25 million stars from Hubble Guide Star Catalogs, over 740,000 galaxies all the way down to 18th magnitude as well as 630,000 Solar System objects. This upgraded version also features new Apollo 11 mission data.

With impressive detail and simulation quality, SkySafari 6 Pro simulates the view from anywhere in the Solar System – including from locations on Earth – and beyond as well as into the universe's past or future. Even more impressive is that you get a real-time review of the rotation of the planets as well as a Telescope Equipment setting that enables you to enter a list of your telescope equipment and get an automatic field of view.

Its high price may put some off, but it's compatible with iPad, iPod Touch and iPhone. Being so useful to all levels of astronomer, we felt that it was worth every penny. There is also the option of purchasing the less involved SkySafari 6 and SkySafari 6 Plus depending on your budget. Whether you're a serious astronomer who wants to control a telescope or a novice who's finding their way around the night sky, we couldn't recommend this app enough.

> "Being so useful to all levels of astronomer, we felt that it was worth every penny"

Book Dr Space Junk vs The Universe

Cost: £22.50 / $27.95 **From:** The MIT Press

A pioneering space archaeologist explores artefacts left behind in space and on Earth, from Moon dust to Elon Musk's red sports car.

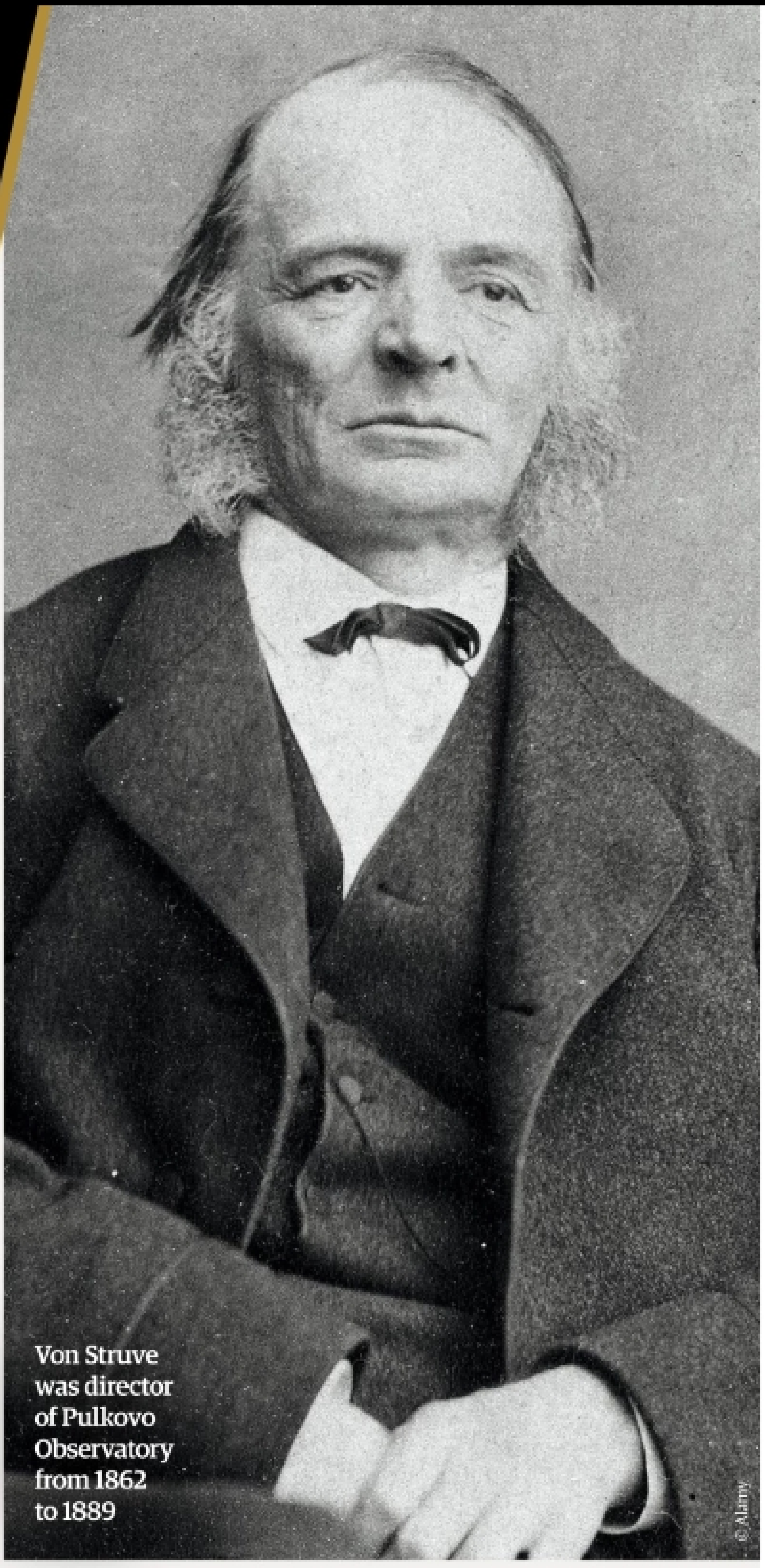
In this book, space archaeologist Alice Gorman examines the artefacts of human encounters with space. These objects, left behind on Earth and in space, can be massive or tiny. They can be bold or hopeful. They raise interesting questions: why did Elon Musk feel compelled to send a red Tesla into space? What accounts for the multiple rocket-themed playgrounds constructed after the Russians launched Sputnik? Gorman – affectionately known as 'Dr Space Junk' – takes readers on a journey through the Solar System and beyond, deploying space artefacts, historical explorations and even the occasional cocktail recipe that make space meaningful.

Engaging and erudite, Gorman recounts her background as a non-space archaeologist and how she became interested in space artefacts. She shows us her own piece of space junk: a fragment of the fuel tank insulation from Skylab, the NASA spacecraft that crash-landed in Western Australia in 1979. She reveals that the conventional view of the Space Race as 'the triumph of the white, male American astronaut' seems inadequate; what really interests her, she says, is how everyday people engage with space. To an archaeologist, objects from the past are significant because they remind us of what we might want to hold onto in the future.

HEROES OF SPACE

Otto Wilhelm von Struve

Like his father, the astronomer was a pioneer in stellar physics almost 200 years ago


Von Struve was director of Pulkovo Observatory from 1862 to 1889

© Alamy

Not quite a household name among astronomers, Otto Wilhelm von Struve made important contributions to the field of astronomy in the late-19th century. It is widely considered that he pioneered the study of double stars, and he was an influential figure at the Pulkovo Observatory, a principal astronomical observatory of the Russian Academy of Sciences located in Saint Petersburg, Russia.

Von Struve was born on 7 May 1819 in Dorpat, now known as Tartu, in modern-day Estonia. However, he later became a Russian citizen, having been deemed a 'foreigner' for the first 24 years of his life. It was clear that he was an intelligent person in his early years, which saw him graduate from the Academy of Dorpat at the age of just 15. The only thing that stopped him from attending university was that he was a year younger than the prescribed age. However, he began attending lectures as a listener at the Imperial University of Dorpat, finally completing his course at the age of 20. Meanwhile, he was helping his father at the Dorpat Observatory.

After von Struve graduated in 1839, he went to the recently opened Pulkovo Observatory and was given the role of assistant director - with the director being his father. At this time Pulkovo flaunted the best optical instrument in the world: a 38-centimetre (15-inch) refractor telescope. With this advanced piece of kit he began scrutinising the realm of stellar astronomy, creating a piece of work titled *The Determination of the Constant of Precession with regard to the Proper Motion of the Solar System.*

He received his masters in astronomy from the University of St Petersburg in 1841, and in 1850 he received the Gold Medal of the Royal Astronomical Society in London. With Pulkovo's revolutionary refractor telescope at his disposal, he was tasked with searching for new double stars and provided unprecedented measurements and details about their behaviour. This is the work that would make him so popular in the world of astronomy, especially when he continued on from his father's work and created the Pulkovo Catalogue of Stellar Coordinates, filled with of thousands of double-star coordinates. When his father fell ill in 1858, von Struve took over management responsibilities, eventually becoming director in 1862. He maintained a firm grasp on that role until his retirement in 1889.

> "With a revolutionary refractor telescope, he was tasked with searching for new double stars"

Pioneering work with double stars wasn't his only area of expertise; he also went on expeditions to view solar eclipses in the mid-19th century, also observing the transits of Venus, nebulae and even publishing work on Uranus' moons, Ariel and Umbriel. Between the years of 1852 and 1889 he was a prominent member of the Russian Academy of Sciences, as well as a member of many European scientific societies, which all benefited from his infectious intelligence. Sadly he fell ill while on his travels through Germany in 1895, passing away on 16 April 1905 in Karlsruhe, Germany.

All About Space

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Printed by William Gibbons & Sons Limited, 26 Planetary Road, Willenhall, Wolverhampton, West Midlands, WV13 3XB

Distributed by Marketforce, 5 Churchill Place, Canary Wharf, London, E14 5HU www.marketforce.co.uk Tel: 0203 787 9060

ISSN 2050-0548

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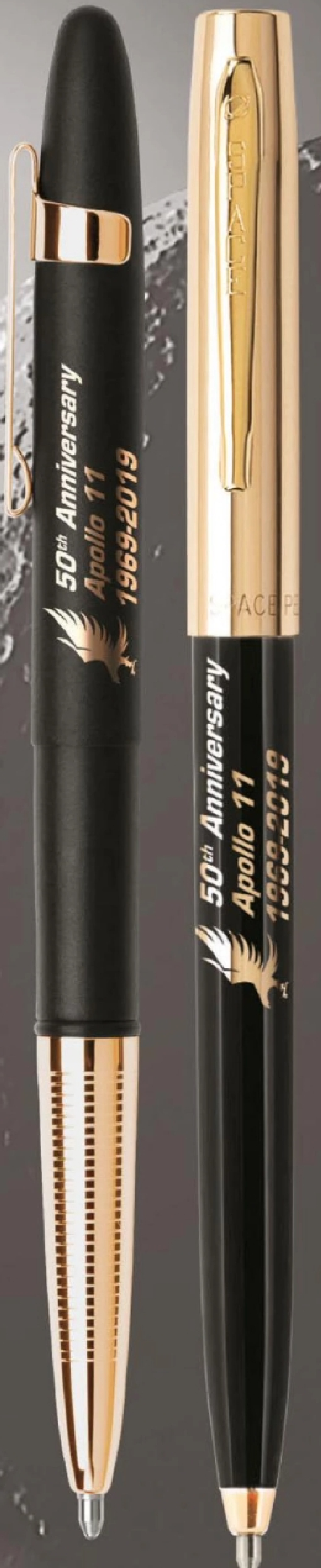

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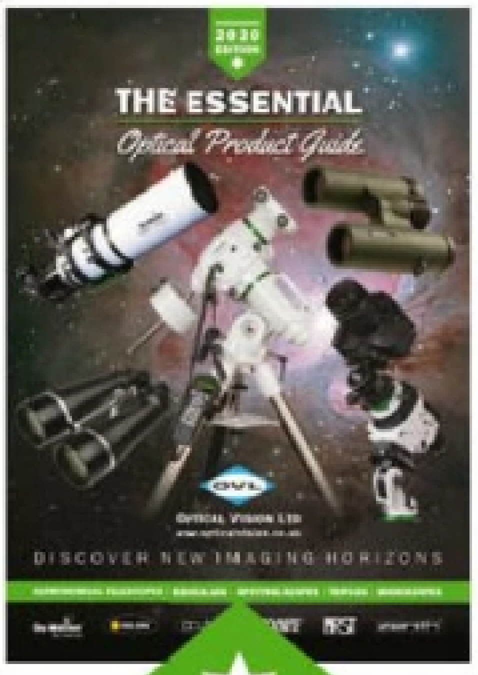

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